2020 BLM Specialist Report on Annual Greenhouse Gas Emissions and Climate Trends

from Coal, Oil, and Gas Exploration and Development on the Federal Mineral Estate

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Executive Summary

The "*2020 BLM Specialist Report on Annual Greenhouse Gas Emissions and Climate Trends*" presents the estimated emissions of greenhouse gases (GHGs) attributable to fossil fuels produced on lands and mineral estate managed by the Bureau of Land Management (BLM). More specifically, this report is focused on estimating GHG emissions from coal, oil, and gas development that is occurring, and is projected to occur, on the federal onshore mineral estate. The report includes a summary of emissions estimates from reasonably foreseeable federal fossil fuel development and production over the next 12 months, as well as longer term assessments of potential federal fossil fuel GHG emissions and the anticipated climate change impacts resulting from the cumulative global GHG burden. The report is an important tool for evaluating the cumulative impacts of GHG emissions from fossil fuel energy leasing and development authorizations on federal onshore mineral estate relative to several emission scopes and base years.

Emissions estimates were developed using fiscal year (FY) 2020 data for both direct and indirect emissions. Direct emissions can result from authorized activities such as drilling or venting, while indirect emissions occur as a consequence of the authorized action and can include activities such as the processing, transportation, and any end-use combustion of the fossil fuel mineral products. The emission estimates are expressed as megatonnes (Mt) of carbon dioxide equivalents (CO_2e) on either a rate or absolute basis. Table ES-1 shows the estimated GHG emissions from actual fossil fuel production from the Federal mineral estate in FY 2020. Table ES-2 shows the 2020 emissions by state, where extraction is the direct portion of the emissions, and processing and transport represent a portion of the indirect emissions along with the end-use estimates.

Table ES-1. Estimated Annual GHG Emissions from Existing Federal Fossil Fuel Production in 2020 (Mt CO_2e)

BLM Authorized Development	Direct	Indirect	End Use	Total
Coal	4.85	27.36	458.74	490.95
Oil	25.00	18.08	136.36	179.44
Gas	20.44	50.51	177.29	248.24
Total 2020 Existing	**50.3**	**95.9**	**772.4**	**918.6**

2020 annual emissions based on fiscal year production data (i.e., Oct. 1 - Sept. 30)

Table ES-2. Estimated Annual Federal Emissions by State - 2020 (Mt CO_2e)

Area	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	50.2766	21.505	74.4534	772.39	918.62
WY	14.5008	4.7627	41.0384	452.84	513.14
NM	23.3699	11.6466	17.25	151.47	203.74
CO	4.7509	1.4989	8.4371	62.58	77.27
UT	1.6932	0.5833	2.4352	40.91	45.62
ND	3.6897	2.0294	1.8776	26.88	34.48
MT	0.4949	0.1584	1.7523	25.59	28
CA	0.7979	0.464	0.1869	4.49	5.94
LA	0.2064	0.0765	0.3712	1.68	2.33
AK	0.1873	0.0812	0.2495	1.38	1.9
TX	0.1553	0.0564	0.2883	1.27	1.77
OK	0.1619	0.0588	0.2003	1.21	1.63
AL	0.1022	0.0194	0.1255	0.83	1.08
AR	0.051	0.0165	0.1095	0.44	0.62
KS	0.0281	0.0113	0.044	0.21	0.29
OH	0.0233	0.0077	0.0487	0.2	0.28
MS	0.0198	0.0115	0.0053	0.11	0.14
NV	0.019	0.0112	0.0025	0.1	0.13
SD	0.0126	0.0063	0.0113	0.08	0.11
MI	0.0077	0.0027	0.0148	0.06	0.08
VA	0.0007	0.0002	0.0016	0.01	0.01
NE	0.0015	0.0009	0.0002	0.01	0.01
KY	0.0009	0.0004	0.0013	0.01	0.01
WV	0.0004	0.0001	0.0008	0	0
PA	0.0003	0.0001	0.0007	0	0
NY	0	0	0.0001	0	0
IL	0.0007	0.0004	0.0001	0	0
ID	0.0001	0	0.0002	0	0

Table ES-3 provides an estimate of (1) present emissions from existing production that is anticipated to keep producing and (2) reasonably foreseeable future GHG emissions, including (a) emissions from previously authorized development that is not currently producing but may begin production and (b) potential new leasing that could begin producing. This table also provides estimated cumulative GHG emissions over the typical production life for existing and new development projected to occur over the next fiscal year. The typical production life for an oil and gas well can vary considerably based on multiple factors but generally ranges from 20 to 25 years. The projected emissions estimates generated in this report are based on a conservative assumption that the production life for new oil and gas wells is 30 years (with decline). The typical production life assumed for coal production is 1 year as most coal is typically produced and consumed in a single year. The annualized emissions rates shown in Table ES-3 are a subset of the life-of-project emissions data, specifically the emissions from year one (i.e., the next 12 months).

Table ES-3. Estimated GHG Emissions from Reasonably Foreseeable Projected Federal Fossil Fuel Production over the Next 12 Months

BLM Authorized Development	Mt CO2e/yr (Annual)				Mt CO2e (cumulative)
	Direct	**Indirect**	**End Use**	**Totals**	**Life-of-Project**
Existing Federal Production					
Coal	5.66	30.47	509.92	546.05	546.05
Oil	18.97	13.73	103.48	136.18	1,062.08
Gas	16.53	40.86	143.40	200.79	2,074.62
Subtotal Existing Production	**41.2**	**85.1**	**756.8**	**883.0**	**4,110.4**
Permitted but NOT yet developed Oil, Gas, and Coal Leases					
Coal	0	0	0	0	0
Oil	24.04	17.39	131.18	172.61	366.42
Gas	7.11	17.56	61.70	86.37	289.77
Subtotal Approved Permits	**31.2**	**35.0**	**192.9**	**259.0**	**656.2**
Potential New Leases					
Coal	0	0	0	0	0
Oil	10.20	7.38	55.62	73.09	192.57
Gas	6.07	15.00	52.65	73.72	322.05
Subtotal Potential	**16.3**	**22.4**	**108.2**	**146.8**	**514.6**
Total Projected Emissions over the next 12 Months					
Coal	5.66	30.47	509.92	546.05	546.05
Oil	53.19	38.49	290.20	381.88	1,621.07
Gas	29.71	73.42	257.75	360.88	2,686.44
Total CO2e	**88.6**	**142.4**	**1,057.9**	**1,288.8**	**4,853.6**

> Emissions are based on life-cycle-assessment (LCA) data factors that are relative to total production and include non-combusted GHGs (e.g., fugitive CH_4).
> Indirect emissions include LCA values for transportation/distribution, processing/refining, but NOT end use (combustion), which is shown separately for illustrative purposes.
> Direct and Indirect emissions are additive for life-cycle accounting but represent a double count for annual reporting.
> Life-of-Project emissions for Oil and Gas are a 30-year declined-projection for each authorization type shown. Coal emissions are based on a single year of forecasted production (see coal discussion in Chapter 4.2).

Table ES-4 provides the long-term cumulative sums of production, energy values, and GHG emissions projected out to year 2050 based on data obtained from the U.S. Energy Information Administration's Annual Energy Outlook 2021 report. The projections are made by multiplying each year of data from the

AEO report by the most current 5-year averages of federal production divided by the 5-year averages of total U.S. production for each fossil fuel mineral type.

Table ES-4. Long-Term (2021 - 2050) Onshore Federal Mineral Projections

Federal Minerals	Production	Energy (Quads)	Emissions (Mt CO_2e)
Coal (MM short tons)	5,325.36	132.7612	10,151.36
Oil (MM b/d)	24.43	51.6835	5,089.09
Gas (Tcf)	117.71	119.2700	8,871.90
Projected Totals	**NA**	**303.71**	**24,112.35**

> 5-year average ratio of fossil fuel historical production data equals federal (ONRR) / U.S. Totals (EIA).
> AEO Reference Case used for series projections, and totals are the sum of the series (2021 - 2050).

Additional details on emissions estimation methodologies and calculation results are presented in Chapters 4 and 5. Chapters 1 through 3 provide background information on the purpose of this document, applicable laws, and the GHGs of interest to the BLM. The remainder of the document (Chapters 6 through 10) provides comparative context for the estimated emissions, the impacts of climate change, and potential mitigation strategies.

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1.0 Introduction

1.1 Purpose

The "***2020 BLM Specialist Report on Annual Greenhouse Gas Emissions and Climate Trends***" provides a detailed assessment of greenhouse gas (GHG) emission trends and potential climate impacts from energy development projects, specifically those that may result from the Bureau of Land Management (BLM) authorized coal, oil, and gas leases and approved development on public lands (including the federal mineral estate) managed by the BLM. This report examines carbon emissions from authorized development of the onshore federal mineral estate in the context of the nation's carbon economy and the relationship between energy generation and climate issues by providing life-cycle estimates of fossil fuel greenhouse gas emissions from that development. The report provides estimates of both direct and indirect emissions from development and consumption of onshore federal fossil fuel minerals, including those fuels that are combusted by end users (when off-lease). This report incorporates current climate science and discussions of scientific values relevant to the context within which the BLM authorizes development of the onshore federal mineral estate. This report is designed to be updated on an annual basis and serves as a tool to track the evolution of climate science and policy inorder to provide decision makers with the best available data to implement management strategies consistent with regulatory requirements.

1.2 Background

Coal, oil, and gas are examples of fossil fuels found in the Earth's crust that formed from decomposing plants and animals. These fuels contain high concentrations of carbon and hydrogen that can be burned for energy. The extraction, production, and consumption of these fossil fuels produce GHGs, particularly carbon dioxide and methane, which in turn trap heat in the atmosphere causing the "greenhouse effect", resulting in an increase in average global temperatures and other climatic changes over time. The BLM's authorization of fossil fuel energy development can result in both direct and indirect emissions of GHGs that contribute to global climate change. Direct emissions can result from authorized activities such as drilling or venting, while indirect emissions occur as a consequence of the authorized action and can include activities such as the processing, transportation, and any end-use combustion of the fossil fuel mineral products.

As the steward of the greatest percentage of federal lands, the BLM manages about 245 million acres of public lands encompassing approximately 10 percent of the nation's total surface area. In addition, the BLM administers the onshore federal mineral estate (subsurface) which covers a total of about 710 million acres from the eastern United States to Alaska (BLM 2020)[1]. In keeping with its multiple use and sustained yield mandate prescribed in accordance with the Federal Land Policy and Management Act (FLPMA) of 1976 and the Mineral Leasing Act (MLA) of 1920 (30 U.S.C. 181 et seq.), the BLM leases minerals including coal, oil, and gas on the onshore federal mineral estate and authorizes development of these leased minerals. Approximately 26.4 million acres of the federal mineral estate have been leased through BLM's coal leasing and oil and gas leasing programs. Slightly less than half (approximately 48%, or 13 million acres) of the leased mineral estate are currently producing federal fossil fuels (coal, oil, gas). Statistics maintained by the Office of Natural Resources Revenue (ONRR) show that approximately 246 million tons of coal, 314 million barrels of oil and 3.3 billion cubic feet of gas were produced from these 13 million acres in 2020, or about 46% of the nation's coal supply, and 7.6% and 9.1% of the nation's oil and gas supply, respectively. **Note:** The total area of onshore federal mineral estate does not imply that economically recoverable quantities of minerals exist at that scale; it is simply an administrative area.

1.3 Using this Report

Consistent with 40 C.F.R. § 1501.12 (Incorporation by reference) and mandates to reduce paperwork, National Environmental Policy Act (NEPA) document preparation time, and overall NEPA document lengths, this report may be incorporated by reference (IBR) into applicable NEPA documents to aid in describing reasonably foreseeable environmental trends in the affected environment (40 CFR § 1502.15), and to provide context for impacts analysis of GHG emissions resulting from the federal action being analyzed. Consistent with the Council on Environmental Quality (CEQ), Department of the Interior regulations and BLM policy, when this report is incorporated by reference, the BLM must cite and summarize this report (see 40 CFR § 1501.12; 43 CFR § 46.135; and BLM Handbook H-1790-1, "NEPA Handbook", chapter 5.2.1) and ensure it is available for inspection by potentially interested persons. In the course of incorporating this report by reference, the NEPA document should also explicitly incorporate all linked content and reference materials used in this report to provide for a complete record. **Note:** This report does not take the place of an analysis and disclosure of emissions at the project level that may be completed for NEPA analysis specific to a decision to lease or authorize development, but this report supplements that analysis by providing an evaluation of cumulative emissions from fossil fuel authorizations on a state and national level.

This report is available in two formats: a static report and a dynamic online tool. The static version is essentially any printed version of the dynamic web tool, and should be used to support the administrative records for applicable federal decisions at the point in time that NEPA analysis is conducted. The web-based version is dynamic and allows for real-time data incorporation and transformations that are not easily replicated in a nondigital format. The web version is built to be interactive and allow readers to quickly explore and find various datasets such that the context and conclusions of the report can be easily understood. Dynamic content contained within the various report elements will load and render applicable datasets based on the user's interaction with the element's control(s). The interactive design means that readers will need to take care to ensure that any dynamic datasets of interest are rendered (i.e., visible) in the document prior to printing the report, as the browser will only print what is rendered. For example, most of the charts in this report allow users to explore multiple datasets, however only the visible dataset is printed. The report will not print all of the available chart configurations for a particular dataset which could number in the hundreds. Users can save individual charts by right clicking and selecting "save image as..." to download a copy, and in most case the data for a rendered chart can be downloaded as well.

This report was prepared by air quality, fluid minerals, and leasing specialists across the BLM, to make a broad but concerted effort to utilize and present the best data and statistics available for estimating emissions associated with BLM-authorized actions in a consistent manner. This data was analyzed using the best available science applicable to the onshore federal mineral estate. As new information and models become available, the BLM will continue to improve and revise its emission estimates, methodologies, and assumptions as appropriate. This report will be updated annually, and each annual version of the report will review the accuracy of the estimates and projections represented in previous versions and will incorporate actual data from the previous year, to calibrate assumptions used in the next year’s emissions estimates and projections and thereby improve the accuracy of each iteration of the report.

1.4 Disclaimer

Much of the sourced information for this report has been obtained, summarized, or linked from the presentations of various governmental agencies, international institutions, and nongovernmental organizations. All information in this report is being provided "as is", and while the authors made every attempt to ensure that the information is timely, complete, accurate, and obtained from reliable sources, the BLM makes no guarantee that it is free of errors or omissions. Hyperlinks contained within the report connect to other websites that are maintained by other Federal Government agencies or nonfederal entities over which the BLM exercises no control. The BLM does not make any representation as to the accuracy or any other aspect of information contained in linked content or data obtained from external application programming interfaces. The projections and evaluations of the data developed and disclosed in this report are presented strictly to display assumptions for analysis and should not be interpreted as an exacting prediction or guarantee of future conditions, emission trends, or as an emissions cap or authorization limit. This report is not intended to, and does not create any right or benefit, substantive or procedural, enforceable at law or in equity by a party against the United States, its departments, agencies, or entities, its officers, employees, agents, or any other person.

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2.0 Relationships to Other Laws and Policies

2.1 Federal Land Policy and Management Act

The Federal Land Policy and Management Act (FLPMA) of 1976 (43 U.S.C. §§ 1701-1785), provides the majority of the BLM's legislated authority, policy direction, and basic management guidance. This act outlines the BLM's role as a multiple use land management agency and provides for management of the public lands under principles of multiple use and sustained yield unless otherwise provided by law. The act states a policy that public lands are to be managed "in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values" (Sec. 102(a)(8)). To fulfill this responsibility, the BLM's land use plans ensure "compliance with applicable pollution control laws, including State and Federal air, water, noise, or other pollution standards or implementation plans" (Sec. 202(c)(8)). Accordingly, BLMs leases and operating permits for fossil fuels require compliance with all state and federal air pollution requirements. FLPMA also gives the BLM authority to revoke or suspend any BLM-authorized activity that is found to be in violation of regulations applicable to public lands and/or noncompliance with applicable state or federal air quality standards or implementation plans, thus ensuring that the BLM can provide for compliance with applicable air quality standards, regulations, and implementation plans (Sec. 302(c)). Thus, for purposes of analysis, the BLM assumes full compliance with applicable state and federal air quality requirements, emissions standards, and related equipment and performance standards in effect at the time of the writing of the report.

2.2 Mineral Leasing Act

The Mineral Leasing Act of 1920, (MLA) as amended (30 U.S.C. 181 et seq.) authorizes and governs leasing of public lands for development of deposits of coal, oil, gas and other hydrocarbons, sulphur, phosphate, potassium and sodium. Section 185 of this title contains provisions relating to granting of rights-of-ways over Federal lands for pipelines. The MLA and the Mineral Leasing Act for Acquired Lands of 1947 give the BLM responsibility for oil and gas leasing of minerals underlying about 700 million acres of BLM-managed surface lands, National Forest System lands, other Federal lands managed by other agencies, and State and private surface lands where the mineral rights underneath were retained by the Federal government. The Federal Onshore Oil and Gas Leasing Reform Act of 1987 (Sec. 5102) amended the MLA (30 USC 226), and directs the BLM to conduct lease sales for each State where eligible lands are available at least quarterly. Leases are first offered for sale at competitive auctions and then are made available non-competitively, for two years, if a qualified bid is not received at the competitive sale.

2.3 National Environmental Policy Act

The National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. § 4321 et seq.) ensures that information on the potential environmental and human impact of federal actions is available to public officials and citizens before decisions are made and before actions are taken. One of the purposes of the act is to "promote efforts which will prevent or eliminate damage to the environment and biosphere," and to promote human health and welfare (Section 2). This act requires that agencies prepare a detailed statement on the environmental impact of the proposed action for major federal actions expected to significantly affect the quality of the human environment (Section 102(C)). In addition, agencies are required, to the fullest extent possible, to use a "systematic, interdisciplinary approach" in planning and decisionmaking processes that may have an impact on the environment (Section 102(A)).

2.4 Council on Environmental Quality

The Council on Environmental Quality (CEQ) is an entity within the executive office of the President that is responsible for coordinating federal efforts to improve, preserve, and protect America's public health and environment. The CEQ oversees the implementation of NEPA by issuing guidance, interpreting regulations, and approving federal agency NEPA procedures.

The CEQ issued final guidance for federal agencies on analyzing GHGs in NEPA documents in 2016 ("Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews"). The CEQ rescinded that guidance in 2017 and released new draft guidance in 2019. On February 19, 2021, pursuant to Executive Order 13990, "Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis", the CEQ rescinded the 2019 draft NEPA guidance on consideration of GHGs and is reviewing, for revision and update, the previously recinded 2016 final guidance. In the interim, the CEQ has advised federal agencies to consider all available tools and resources in assessing GHG emissions and climate change effects of their proposed actions, including the previously rescinded 2016 GHG guidance.

2.5 Executive Orders

Executive orders (EOs) and memoranda issued in 2021 address the climate crisis and focus on GHG emission reductions and increased renewable energy production. The orders rescind previous CEQ guidance on analysis of GHG emissions, with the goal of reviewing, revising/updating, and issuing new guidance on the consideration of GHGs and climate change in NEPA analysis. Finally, the methodologies for the calculation of the social cost of carbon, nitrous oxide, and methane, as well as the incorporation of this information in NEPA and other analyses are key subjects selected for review and potential revision. The following is a summary of two of the EOs:

EO 13990 - Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis (January 25, 2021): Directs all executive departments and agencies to immediately commence work to confront the climate crisis with the goal to improve public health and the environment. Two key directives in this EO are (1) the establishment of an Interagency Working Group on the Social Cost of Greenhouse Gases tasked with developing and promulgating costs for agencies to apply during cost-benefit analysis and (2) the recission of the CEQ draft guidance, entitled "Draft National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions," 84 FR 30097 (June 26, 2019). The EO also directs the Secretary of the Interior to place a temporary moratorium on all oil and gas activities in the Arctic National Wildlife Refuge, revokes the permit for the Keystone XL pipeline, and requires all agency heads to review any agency activity under the prior administration to ensure compliance with the current administration's environmental policies.

EO 14008 - Tackling the Climate Crisis at Home and Abroad (January 27, 2021): Directs the executive branch to establish climate considerations as an element of U.S. foreign policy and national security and to take a government-side approach to the climate crisis. This EO reaffirms the decision to rejoin the Paris Agreement, commitments to environmental justice and new clean infrastructure projects, establishing a National Climate Task Force, and puts the U.S. on a path to achieve net-zero emissions by no later than 2050. Specific directives for the Department of the Interior and the BLM include increasing renewable energy production on public lands and waters, performing a comprehensive review of potential climate and other impacts from oil and natural gas development on public lands, establishing a civilian climate corps, and working with key stakeholders to achieve a goal of conserving at least 30 percent of the nation's lands and waters by 2030.

2.6 United States Global Change Research Program

The United States Global Change Research Program (USGCRP) is a federal program that was established by Presidential Initiative in 1989 and mandated by Congress in the Global Change Research Act of 1990 (Public Law 101-606; 104 Stat. 3096-3104). The Global Change Research Act mandates that the USGCRP deliver a report, known as the National Climate Assessment (NCA) to Congress and the President no less than every 4 years. Thirteen federal agencies collaborate to advance understanding of the changing Earth system and maximize efficiencies in federal global change research. The fourth, and most recent report, NCA4, was released in two volumes in 2017 and 2018, and elements of each volume have been summarized and incorporated into this report to describe the known effects of climate change. The Fifth National Climate Assessment (NCA5) is currently underway, with anticipated delivery in 2023.

2.7 Clean Air Act

GHGs are considered air pollutants and are regulated under the Clean Air Act (42 U.S.C. § 7401 et seq.). The U.S. Supreme Court first ruled that GHGs are air pollutants in 2007 (Massachusetts v. Environmental Protection Agency, 549 U.S. 497 (2007)) and instructed the Environmental Protection Agency (EPA) to determine if GHG emissions endanger public health and welfare. In April 2009, the EPA issued its endangerment finding; in May 2010 issued its GHG Tailoring Rule (40 CFR Part 51, 52, 70, et al.); and in January 2011, the EPA began regulating GHGs under its Prevention of Significant Deterioration (PSD) and Title V permitting programs.

The EPA set initial emissions thresholds for PSD and Title V permitting applicable to stationary sources that emit greater than 100,000 tons of carbon dioxide equivalents (CO_2e) per year (e.g., some power plants, landfills, and other sources) or modifications of major sources with resulting emissions increases greater than 75,000 tons of CO_2e per year. However, in 2014, the U.S. Supreme Court (Utility Air Regulatory Group v. EPA, 573 U.S. 302, 134 (2014)) held that the EPA may not treat GHGs as an air pollutant for purposes of determining whether a source is a major source required to obtain a PSD or Title V operating permit under the CAA.

In 2009, the EPA published a rule for the mandatory reporting of GHGs (40 CFR Part 98, Subpart C), which is referred to as the Greenhouse Gas Reporting Program (GHGRP). This rule establishes mandatory GHG reporting requirements for owners and operators of certain facilities that directly emit GHGs as well as for certain indirect emitters, or suppliers. For suppliers, the GHGs reported are the quantity that would be emitted from combustion or use of the products supplied. The rule provides a basis for future EPA policy decisions and regulatory initiatives regarding GHGs. Facilities are generally required to submit annual reports under 40 CFR Part 98 if annual emissions exceed 25,000 metric tons of CO_2e per year.

2.8 Specific Regulatory Requirements

Various laws and regulations have been implemented by air quality regulatory agencies that limit GHG emissions from mining activities and oil and gas production, transmissions, and distribution facilities. Although many of the laws and regulations subsequently summarized focus on limiting criteria air pollutants or precursors such as volatile organic compounds, they also have a secondary benefit of limiting GHG emissions[2].

Federal Rules

Federal regulations require that GHG emissions related to coal be quantified and reported under 40 CFR 98. 40 CFR 98, Subpart FF, requires underground coal mines to report methane emissions. Coal-fired electric power plants are required to continuously monitor carbon dioxide emissions under 40 CFR 98, Subpart D, and submit quarterly emission reports to EPA under 40 CFR 75. Petroleum and natural gas systems are also required to report GHG emissions under 40 CFR 98, Subpart W.

The Mine Safety and Health Administration requires methane monitoring in underground mines and sets limits on methane concentrations to protect the life, health, and safety of the miners, but it does not limit methane emission amounts.

The EPA has established emissions control requirements in the New Source Performance Standards (NSPS) at 40 CFR Part 60 that apply to coal, oil, and natural gas production facilities. 40 CFR 60, Subparts OOOO and OOOOa, for example, serve to control methane emissions from oil and natural gas industry sources. Subpart OOOOa requires reduced emissions completions ("green" completions) on new hydraulically fractured gas wells as well as emissions controls on pneumatic controllers, pumps, storage vessels, and compressors. Other relevant NSPS requirements under 40 CFR Part 60 include:

- Subpart GG – Standards of Performance for Stationary Gas Turbines
- Subpart IIII – Standards of Performance for Stationary Compression Ignition Internal Combustion Engines
- Subpart JJJJ – Standards of Performance for Stationary Spark Ignition Internal Combustion Engines
- Subpart K – Standards of Performance for Storage Vessels for Petroleum Liquids for which Construction, Reconstruction, or Modification Commenced after June 11, 1973 & prior to May 19, 1978
- Subpart Ka – Standards of Performance for Storage Vessels for Petroleum Liquids for which Construction, Reconstruction, or Modification Commenced after May 18, 1978 & prior to July 23, 1984
- Subpart Kb – Standards of Performance for Storage Vessels for Petroleum Liquids for which Construction, Reconstruction, or Modification Commenced after July 23, 1984
- Subpart KKK – Standards of Performance for Equipment Leaks of VOC from Onshore Natural Gas Processing Plants for Which Construction, Reconstruction, or Modification Commenced After January 20, 1984 and on or Before August 23, 2011
- Subpart KKKK – Standards of Performance for Stationary Combustion Turbines
- Subpart OOOO – Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution for which Construction, Modification, or Reconstruction Commenced after August 23, 2011
- Subpart OOOOa – Standards of Performance for Crude Oil and Natural Gas Production, Transmission, and Distribution for which Construction, Modification, or Reconstruction Commenced on or after September 18, 2015
- Subpart TTTT - Standards of Performance for Greenhouse Gas Emissions for Electric Generating Units
- Subpart Y - Standards of Performance for Coal Preparation and Processing Plants

In addition to the EPA's rules, the BLM issued a "Notice to Lessees and Operators of Onshore Federal and Indian Oil and Gas Leases" (NTL-4a) regarding the royalty free venting and flaring of gas from oil and gas wells. Gas from a natural gas well may not be vented or flared except where the loss is defined as unavoidably lost production or considered "authorized venting and flaring of gas." Gas from oil wells may not be vented or flared except where the loss is defined as unavoidably lost production, considered "authorized venting and flaring of gas," or approved by the BLM based on consideration of an evaluation report or action plan. Authorized venting and flaring of gas includes emergency releases, well purging and evaluation tests, initial production tests, and routine or special well tests.

Alaska

The State of Alaska established administrative code 18 AAC 50 which describes Air Quality Control for the state. Under 18 AAC 50.040, the state adopted emissions control standards established in 40 CFR Part 60 as they apply to a Title V source.

California

California's "Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities" (17 CCR 95665 – 95677) sets equipment standards, testing requirements, and leak detection requirements for crude oil and gas production and storage facilities. Requirements are similar to federal standards under 40 CFR 60, Subpart OOOOa, but are more stringent, cover additional types of equipment and operations, and apply to existing as well as new sources. Although the rule is focused on controlling GHG emissions, the standards and monitoring employed also control volatile organic compound and hazard air pollutant emissions.

California Code of Regulations Regulations (14 CCR 1700 – 1883), govern the siting, development, operation, monitoring, inspection, stimulation, and abandonment of oil and gas production wells and gas storage wells. The regulations are intended to protect the environment, preserve safety, and prevent loss or waste of produced oil and gas. Although they are not specifically designed to reduce GHG emissions, provisions limiting loss and waste of gas and requiring effective abandonment reduce methane emissions from wells in California.

California's "Mandatory Greenhouse Gas Emissions Reporting" (17 CCR 95100-95163) requires petroleum and natural gas system operators to report their annual GHG emissions to the California Air Resources Board.

Colorado

The Colorado Oil and Gas Conservation Commission (COGCC) regulates oil and gas related activities in Colorado. In addition, the Colorado Department of Public Health and Environment (CDPHE) has regulations, reporting, and permitting requirements for oil and gas operations in Colorado. The BLM currently requires all federal oil and gas development and operations in Colorado to obtain the necessary permits and follow the applicable rules and regulations set forth by the COGCC and CDPHE.

Recent Colorado legislative actions have resulted in rules and regulations aimed at inventorying and reducing GHG emissions to meet Colorado's GHG emissions goals. Colorado Senate Bill 19-096 (SB 96), addressing GHG emissions data collection, and House Bill 19-1261 (HB 1261), addressing statewide GHG reduction goals, were signed into law on May 30, 2019. SB 96 directs the Air Quality Control Commission (AQCC) to update the statewide inventory at least every 2 years and to adopt rules requiring monitoring and public reporting of GHG emissions in support of state GHG reduction goals. The AQCC adopted GHG inventory and reporting requirements for oil and gas under Regulation 7 in December 2019 and September 2020 and adopted comprehensive statewide GHG reporting rule under Regulation 22 in May 2020, which are in line with the reporting protocols under EPA's Greenhouse Gas Reporting Program (GHGRP). Initial reporting under these requirements will begin in early-to-mid-2021, and full reporting will begin in 2022. Once these reporting requirements are fully implemented, it is expected that future inventories will reflect improved and more accurate data based on direct reporting which will better inform progress towards state GHG reduction goals. It is also anticipated that a more complete understanding of emissions sources, increased onsite monitoring, and the growing availability of aerial detection methods will allow for further refinement of future inventories.

Future rules and regulations may further affect oil and gas development and operations on the federal mineral estate in Colorado. In January 2021, Colorado published its GHG Pollution Reduction Roadmap report to describe pathways and strategies for achieving goals described in HB 1261. The report's summary of near-term actions to reduce GHG emissions projects that progress towards Colorado's 2025 and 2030 GHG emissions reduction goals is feasible. However, it will require increasing renewable electricity generation to achieve an 80% reduction below 2005 emissions levels by 2030, reducing methane emissions from the oil and gas sector more than 50% by 2030, increasing investments in energy efficiency, and expanding electrification of buildings and industry. Specifically, for oil and gas, the report describes two near-term regulatory actions that would likely need to occur in order to achieve Colorado's short-term (2030) goal to reduce emissions relative to the 2005 baseline, by approximately 12.2 MMT of CO_2e. First, the AQCC would need to require the oil and gas industry to achieve a 33% reduction in methane emissions by 2025 and over a 50% reduction by 2030. Second, the COGCC would need to implement new rules that eliminate routine flaring, require minimizing emissions, and track preproduction and production emissions.

Montana

The Montana Board of Oil and Gas Conservation (MBOGC) regulates oil and gas exploration and production in the state. MBOGC regulations related to air impacts from oil and gas operations can be found in Title 36, Chapter 22 of the Administrative Rules of Montana (ARM) and include regulation 36.22.1207 which prohibits the storage of waste oil and oil sludge in pits and open vessels. The Montana Department of Environmental Quality (MDEQ) administers rules and regulations to implement the Montana Environmental Policy Act and the Montana Clean Air Act. MDEQ rules for air emissions from oil and gas operations can be found in Title 17, Chapter 8 of the ARM and include requirements for controlling volatile organic compound vapors at a 95% or greater control efficiency, loading and unloading of hydrocarbon liquids using submerged fill technology, and equipping internal combustion engines with nonselective catalytic reduction or oxidation catalytic reduction.

New Mexico

The New Mexico Environment Department has developed the "Oil and Natural Gas Regulation for Ozone Precursors," (20.2.50.1 NMAC), which is anticipated to go into effect March 2022. Approximately 50,000 wells and associated equipment will be subject to this regulation. It is anticipated that the regulation will annually reduce volatile organic compound (VOC) emissions by 106,420 tons, nitrogen oxide emissions by 23,148 tons, and methane emissions by 200,000 to 425,000 tons. The regulation includes emissions reduction requirements for compressors, engines and turbines, liquids unloading, dehydrators, heaters, pneumatics, storage tanks, and pipeline inspection gauge (PIG) launching and receiving. The regulation also encourages operators to stop venting and flaring and use fuel cells technology to convert CH_4 to electricity at the well site and incentivizes new technology for leak detection and repair.

North Dakota

The North Dakota Department of Mineral Resources' Oil and Gas Division regulates the drilling and production of oil and gas and includes regulations that ban the venting of natural gas and require that vented casinghead gas be burned through a flare (North Dakota Administrative Code 43-02-03-45). The North Dakota Industrial Commission (NDIC) has jurisdiction over the volume of gas flared at a well site to conserve mineral resources and established Order No. 24665 for reducing gas flaring. The order requires producers to submit a gas capture plan with every drilling permit application. The North Dakota Department of Environmental Quality's Division of Air Quality has established permitting and reporting requirements for oil and gas facilities under North Dakota air pollution control rules, Chapter 33.1-15-20, and submerged fill and flare requirements in Chapter 33.1-15-07.

Utah

The Utah Department of Environmental Quality established administrative code R307-500 which applies to all oil and natural gas exploration, production, and transmission operations; well production facilities; natural gas compressor stations; and natural gas processing plants in Utah. These rules adopt emissions control standards established in 40 CFR Part 60, Subpart OOOO. Controls are required for pneumatic controllers, venting and flaring, tank truck loading, storage vessels, dehydrators, VOC control devices, stationary natural gas engines, and leak detection and repair requirements.

Wyoming

The Wyoming Department of Environmental Quality established Wyoming Air Quality Standards and Regulations (WAQSR). Chapter 6, Section 2 and Chapter 3, Section 6 of those regulations apply to all oil and natural gas exploration, production, and transmission operations; well production facilities; natural gas compressor stations; and natural gas processing plants in Wyoming. These rules adopt emissions control standards established in 40 CFR Part 60, Subpart OOOO. Controls are required for pneumatic controllers, venting and flaring, tank truck loading, storage vessels, dehydrators, VOC control devices, stationary natural gas engines, and leak detection and repair requirements.

Note: This report is not a legal treatise, analysis, or opinion. The statutes and regulations governing the BLM and mineral operations on federal lands speak for themselves. Information about legal requirements summarized in this report is not intended to be comprehensive, but rather is included for convenience of analysis.

* * *

3.0 Greenhouse Gases

Gases that trap heat in the atmosphere are called greenhouse gases (GHGs). Current ongoing global climate change is caused, in part, by the atmospheric buildup of GHGs, which may persist for decades or even centuries. Since the start of the Industrial Revolution, human activities have increased GHG emissions substantially above historical background levels.

The primary GHGs emitted by natural and anthropogenic sources include water vapor, carbon dioxide, methane, ozone, nitrous oxide, and chlorofluorocarbons. Water vapor is the largest contributor to the natural greenhouse effect. On average, water accounts for about 60% of the warming effect. However, water vapor is fundamentally different from other GHGs in that it can condense and rain out when it reaches high concentrations, and the total amount of water vapor in the atmosphere is in part a function of the earth's temperature (EPA 2019). Water vapor has a short residence time of approximately 10 days in the atmosphere. While water vapor does have a warming effect on the Earth, water vapor does not control the Earth's temperature. Instead, water vapor concentrations in the atmosphere are controlled by the Earth's temperature (ACS 2021)[3]. More water evaporates from the earth at higher temperatures, which increases the amount of moisture in the clouds that eventually falls as precipitation.

Anthropogenic GHGs are commonly emitted air pollutants that include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several fluorinated species of gases such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Carbon dioxide is by far the most abundant, and more over two thirds of the man-made CO_2 emission in the U.S. come primarily from the transportation and electricity production sectors. Methane from human activities accounts for approximately 10% of total U.S. GHG emissions and results from primarily agriculture and natural gas and petroleum systems. Nitrous oxide emissions from agriculture, fuel combustion, and industrial sources account for approximately 7% of the total U.S. GHG emissions. Fluorinated gases are powerful GHGs that are emitted from a variety of industrial processes and are often used as substitutes for ozone-depleting substances (i.e., chlorofluorocarbons, hydrochlorofluorocarbons, and halons), but they are not typically associated with BLM-authorized activities and, as such, will not be discussed further in this report. This report will address the three major GHGs associated with BLM's fossil energy development authorizations, namely CO_2, CH_4, and N_2O. **Note:** Not all of the emissions estimates contained in this report include separate values for each gas due to data limitations, particularly where some of the methodologies employed combine these gases into a single CO_2 equivalent output that the BLM cannot separate.

Each of these gases can remain in the atmosphere for different lifetimes, ranging from about a decade to thousands of years. As a result, these gases become well mixed such that their measurement in the atmosphere is roughly the same all over the Earth, regardless of the source or origin of the emissions. For this reason, global GHG emissions are the most useful basis for the cumulative analysis of emissions related to BLM actions. Unlike other common air pollutants, the ecological impacts that are attributable to the GHGs are not the result of localized or even regional emissions but are entirely dependent on the collective behavior and emissions of the world's societies.

3.1 Carbon Dioxide (CO_2)

Of the primary GHGs, CO_2 is the most widely occurring. It is a major component of natural carbon cycling in the terrestrial biosphere including photosynthesis (CO_2 uptake by plants) and respiration (CO_2 release by plants, animals, and microorganisms), decomposition, and ocean releases. Carbon dioxide is emitted from human activities including the combustion of fossil fuels (i.e., coal, oil, and natural gas), solid waste, deforestation and wood products manufacturing, and from certain chemical reactions such as steam reforming for the production of hydrogen and calcination for the production of cement clinker. Carbon dioxide emissions accounted for 81% of the total U.S. GHG emissions in 2018 (EPA 2021)[4]. Global ambient CO_2 concentrations increased to an average of 416.5 parts per million (ppm) in 2020 (NOAA 2020). This average is estimated by the National Oceanic and Atmospheric Administration (NOAA) to be the highest average concentration of global CO_2 in the past 800,000 years (Lindsey 2020)[5]. This represents a 47% increase since the beginning of the Industrial Age, when the concentration was near 280 ppm, and an 11 percent increase since 2000, when it was near 370 ppm.

The lifetime of CO_2 in the atmosphere varies between 20 to 1,000 years and is difficult to determine precisely because several processes remove it from the atmosphere. On average, approximately 50% of the CO_2 released into the atmosphere from the burning of fossil fuels remains in the atmosphere while the other 50% is absorbed by plants and trees and certain areas of the ocean (NOAA 2015)[6].

3.2 Methane (CH_4)

Methane is a powerful GHG that is more than 25 times more effective at trapping heat in the atmosphere than CO_2. According to the EPA, methane concentrations in the atmosphere have more than doubled in the last two centuries, largely due to human-related activities. Methane emissions accounted for 9.5% of U.S. GHG emissions in 2018. Methane is emitted during the production and transportation of coal, natural gas, and oil. It is also produced biologically under anaerobic conditions in ruminant animals, wetlands, landfills, and wastewater treatment facilities. In addition, fertilizer use, agriculture, and changes in land use (e.g., from forest to grazing) are major sources of CH_4 in the atmosphere.

3.3 Nitrous Oxide (N_2O)

Nitrous oxide is produced by biological processes that occur in soil and water and by a variety of anthropogenic activities in the agricultural, energy, industrial, and waste management fields. While total N_2O emissions are much lower than CO_2 emissions, N_2O is nearly 300 times more powerful than CO_2 at trapping heat in the atmosphere. Since 1750, the global atmospheric concentration of N_2O has risen by approximately 22% (WMO 2018)[7]. The main anthropogenic activities producing N_2O in the United States are agricultural soil management, stationary fuel combustion, manure management, fuel combustion in motor vehicles, and adipic acid production.

3.4 Global Warming Potential

The impact of a given GHG on global warming depends both on its radiative forcing and how long it lasts in the atmosphere. Each GHG varies with respect to its concentration in the atmosphere and the amount of outgoing radiation absorbed by the gas relative to the amount of incoming radiation it allows to pass through (i.e., radiative forcing). Different GHGs also have different atmospheric lifetimes. Some, such as methane, react in the atmosphere relatively quickly (on the order of 12 years); others, such as carbon dioxide, typically last for hundreds of years or longer. Climate scientists have calculated a factor, known as the global warming potential (GWP), for each GHG that accounts for these effects.

The GWP is used as a conversion factor to convert a mixture of different GHG emissions into carbon dioxide equivalents (CO_2e). Specifically, GWP is a measure of how much energy the emissions of 1 ton of a GHG will absorb over a given period, relative to 1 ton of CO_2 in the same timeframe. The larger its GWP, the more the specific gas warms the Earth as compared to CO_2. The GWP for CO_2 is defined as 1 regardless of the timeframe, because the gas is being used as the reference. The GWP values are updated periodically to account for changing concentrations in the atmosphere and as new estimates on energy absorption or atmospheric lifetime for each gas become available.

GWPs have been developed over different time horizons including 20-year, 100-year, and 500-year for several GHGs. The GWP for a relatively short-lived GHG, such as CH_4, is larger over a short periods (for example, 20 years) than it is over a longer period (such as 100 years) because most of the CH_4 will have reacted away well before 100 years have passed. Conversely, very long-lived GHGs have a 20-year GWP that is lower than the 100-year GWP because the time integrated radiative forcing is less (relative to CO_2) over the shorter time interval. As a result of various complex feedbacks in the earth-atmosphere system, GWPs can be only roughly estimated; according to the Intergovernmental Panel on Climate Change (IPCC), GWPs have a large uncertainty: ±30 percent and ±39 percent for the 20-year and 100-year CH_4 GWPs, respectively, and ±21 percent and ±29 percent for the 20-year and 100-year N_2O GWPs, respectively (IPCC 2013). The choice of emission metric and time horizon depends on type of application and policy context; hence, no single metric is optimal for all policy goals. Also, no single metric adequately represents the global warming effects of GHG's due to their differing amounts of climate forcing, atmospheric lifetimes, and emissions profiles.

For the purposes of this report, the BLM is using the IPCC Fifth Assessment Report (AR5) GWP values for CH_4 and N_2O (shown in Table 3-1), as these values are commonly used by other entities in emissions inventories and reporting requirements, and by the EPA in its climate science communications. The AR5 values also allow for relative comparisons across the multiple sources of data and scopes discussed in this report. The IPCC is now in its sixth assessment report cycle, in which it is producing the Sixth Assessment Report (AR6) with contributions by its three Working Groups to a Synthesis Report, three Special Reports, and a refinement to its latest Methodology Report. The Synthesis Report will be the last of the AR6 products, currently due for release in 2022. Working Group I has recently released its report entitled, Climate Change 2021: The Physical Science Basis, which includes updated GWPs. As these GWPs are adopted in other agency's reporting requirements, inventories, and communications, the BLM will utilize them to allow for accurate comparisons. There are references to emission data or aggregated emissions in this report that are developed by entities that use different GWPs than those presented in this section. Any external emissions data (e.g., EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018, which uses AR4 GWP values) are being presented at face value, meaning that BLM is not attempting to convert those emissions to the GWP basis presented in this report. These potential differences in the different GWPs used in various reports may introduce small numerical errors when comparing emissions on a relative basis. **NOTE:** Readers are encouraged to investigate additional information provided by other agencies, such as Annex 6 of the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks, to understand the differences in total GWP-weighted emissions reported by these agencies.

The BLM uses the 100-year time horizon for GWPs for the emissions calculated in this report and most of the report metrics, to be consistent with the scientific and regulatory communities that develop climate change assessments and policy. The 100-year GWP (GWP100) was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol and is now used widely as the default metric by researchers and regulators. In addition, the EPA uses the 100-year time horizon in its annual inventory, GHGRP, and uses the GWPs and time horizon consistent with the IPCC Fifth Assessment Report.

The 100-year time horizon allows the BLM to compare GHG emissions from its authorized coal, oil, and gas development to other available state and national emissions inventories which also use 100-year GWPs. This timeframe also more fully accounts for any climate feedbacks (discussed in chapter 8), as evidenced by the differences in the GWPs shown in Table 3-1, where greater climate feedbacks are expected to occur further in time away from the point of initial perturbation (emissions) of the climate system. The 100-year timeframe provides a 1-to-1 basis of comparison for the metrics most often used to discuss climate change in the literature in terms of emissions, model results, impacts, and potential emission targets and is therefore more meaningful and understandable for the purposes of this analysis as compared to any other available GWP timeframe. **Note:** Unless otherwise noted, the BLM uses GWP emissions factors inclusive of climate feedbacks to calculate all of the CO_2e estimates in this report.

Table 3-1. Global Warming Potentials

GHG Species	Atmospheric Lifetime (years)	GWP 20-year (w/o feedbacks)	GWP 20-year (w feedbacks)	GWP 100-year (w/o feedbacks)	GWP 100-year (w feedbacks)
CO_2	20 - 1,000	1	1	1	1
CH_4	12.4	84	88	28	36
N_2O	121.0	264	268	265	298

> Data Source: IPCC 2013 [8], CH_4 value is for fossil methane.
> Carbon dioxide's lifetime is shown as a range because the gas is not destroyed over time and is transferred between the ocean–atmosphere–land system at varying rates.
> CO_2's GWP includes its own climate feedbacks.

* * *

4.0 Methods and Assumptions

This report contains estimates of both direct and indirect (including downstream combustion) emissions from BLM-authorized fossil fuel development on the federal mineral estate for the three primary GHGs of concern (CO_2, CH_4, N_2O). In addition, the estimated emissions are aggregated at different scales for comparison to emissions reports and inventories completed by other entities at state, national, and global scales and for relevant industrial sectors. Estimated emissions from BLM-authorized activities are aggregated by BLM state administrative units for comparison to state emissions inventories and to put the scale of emissions into context.

The emissions estimates are also presented at two cumulative scales; geographic and temporal. The geographic cumulative scale is the federal onshore mineral estate managed by the BLM. The temporal cumulative scales include estimated emissions from total federal mineral production projected for the next 12 months, the life-of-project emission estimates associated with the 12-month projections, and the long-term emissions from the portion of energy demand estimated to be met from the federal mineral estate out to year 2050 using data from the Energy Information Administration. The estimates provide a baseline to compare emissions from BLM-authorized development with those of the broader economy (national and global) and illustrate the degree to which federal fossil fuel mineral development contributes to projected GHG emissions and therefore to climate change. The term direct is used here to describe emissions from fossil fuel mineral development and production-related activities authorized by the BLM that typically take place on leased acres of the federal mineral estate. Direct emissions could result from a variety of activities, such as lease exploration, access road construction, well pad or coal mine development, well drilling and completions, recurring maintenance and production equipment operations, and site reclamation. Indirect emissions are those that result from activities outside of the BLM's oversight authority, such as off-lease infrastructure development and maintenance, transportation and distribution, processing and refining, and the end use (including combustion) of any federal minerals produced. End use (indirect, typically combustion) emissions make up the majority of GHG emissions related to federal energy resource development. The sum of the direct and indirect GHG emissions from fossil fuel mineral production and end use is also known as a life-cycle assessment (LCA).

As part of the full life-cycle assessment this report also includes estimates of projected emissions on both a short-term and long-term basis; in which the short-term estimates are based on reasonably foreseeable development trends derived from leasing and production statistics (shown in Table 4-8), and the long-range estimates are based on the analysis of energy market dynamics developed by the U.S. Energy Information Administration (EIA) in its Annual Energy Outlook (AEO) report. Together, the estimates are designed to provide relevant, well-supported, and factual information that is intended to fully account for GHG emissions from BLM authorizations to develop the federal mineral estate.

4.1 Emissions Factors and Production Data

To characterize direct and certain indirect GHG emission estimates in this report, the BLM is applying a combination of published LCA data, other studies and statistics, and assumptions for each fossil fuel type. The LCA data presented in this report are meant to broaden the analysis of the potential emissions that could result from BLM management of the onshore federal mineral estate. While this approach depicts the energy-in/energy-out emissions calculus, LCA accounting is not accurate in terms of the true GHG burden federal minerals represent. For example, adding up all of the energy life cycle emissions inventories prepared for fossil fuel mineral development would result in totals greater than the levels reported at national scales (e.g., EPA's National Emissions Inventory Report). This is because LCA accounting for each mineral can lead to double-counting effects when the results of each separate mineral type are added (Lenzen 2008)[9]. Ultimately, it is known that a portion of the mineral production will be used to obtain more minerals. For example, petroleum is used and accounted for throughout coal's life-cycle in the form of combustion from mining and transportation activities, and has thus been double counted. For any accounting period, there can be no greater sum of emissions than that for which the supply of each mineral type can provide. In general, this means that the total federal GHG burden on the evnvironment is best described by the end use, or downstream combustion portion of the disclosed accounting, plus any fugitive emissions that result from fossil mineral processes prior to end use.

The end-use phase emissions for oil and gas (assumed combustion) are estimated using EPA emissions factors from appendix Tables C-1 and C-2 of 40 CFR Part 98, Subpart C as shown in the tables 4-4 and 4-6 (oil and gas only). The EPA factors were chosen to represent the downstream portion of these life-cycle emissions since they provide a relatively straightforward basis for estimating the consumption of each fuel for which the actual downstream transformation or use is relatively unknown compared to the assumptions and specificity used in the referenced LCA data. Coal is an exception here; the BLM uses a combination of LCA data and internal assessments to represent these emissions (subsequently described).

Additionally, some of the LCA references contain estimates for systemic losses of methane (i.e., fugitive emissions). When such data is available, the BLM back-calculates the fugitive losses from the direct emissions to more fully account for emissions from BLM authorized development.

Fossil fuel production is the primary input used in the LCA methodology, and generally in this report. The BLM is using data and statistics from the Energy Information Administration and the Office of Natural Resources Revenue (ONRR), both of which provide production accounting services for domestic fossil fuel minerals to estimate report year emissions on a fiscal year basis (when such data exists).

4.2 Coal

Virtually all coal produced in the U.S. is classified as either thermal (steam coal) or metallurgical (met or coking coal). Steam coal has a variety of energy-related uses in several sectors of the economy, including as a primary fuel for baseload electrical generating plants. Met coal is used (indirectly, as coke) as a fuel and reactant in steel production blast furnaces. Regardless of classification, the BLM is unaware of any noncombustion or non *de minimis* uses for coal stocks and is thus assuming 100% combustion of all federal coal produced.

To estimate the LCA emissions associated with federal coal production, this report relies on data obtained from several sources to adequately capture the variability of mine activities occurring at regional scales. The estimates use production metrics representative of operational mines (underground and surface) in each state to evaluate the GHG emissions profiles for extraction, processing, venting, transport, and end use (combustion). For Wyoming, Montana, and North Dakota, life-cycle emission factors developed by the Department of Energy's National Energy Technology Laboratory (NETL)[10] to evaluate emissions for production, export to Asia, and use of Powder River Basin coal for power generation were applied to state-specific production data. For New Mexico, Oklahoma, and Alabama, NETL life-cycle emission factors for U.S. coal-fired power plants[11] were used along with state-specific production data. For Colorado and Utah, the BLM used detailed internal data from operational mines (both underground and surface) to evaluate LCA GHGs. A summary of the emissions factors derived for each state where BLM authorizes coal leasing are presented in Table 4-1. An analysis of the factors suggests that the average cradle-to-gate emissions from mining activities (production, direct emissions), coal transport, and offsite processing/handling (part of indirect emissions) make up approximately 6.1% of the total CO_2e emissions related to coal's lifecycle, while combustion (indirect) makes up the remainder (approximately 93.9%). These results are consistent with other external data sources researched[12] in preparation for this report, and as such the data estimates are deemed reasonable for estimation purposes.

Table 4-1. GHG Emissions Factors for Federal Coal Production (kg CO_2e/ton)

Category	Direct	Indirect	End Use	Total
Federal Production Weighted Average	21.16	111.20	1,855.82	1,988.18
State				
Wyoming	14.88	118.12	1,773.23	1,906.23
Montana	14.88	118.12	1,773.23	1,906.23
Utah	26.08	41.96	2,502.47	2,570.51
Colorado	61.98	53.75	3,101.93	3,217.66
North Dakota	14.88	118.12	1,773.23	1,906.23
New Mexico	298.63	12.57	2,220.17	2,531.37
Oklahoma	298.63	12.57	2,220.17	2,531.37
Alabama	298.63	12.57	2,220.17	2,531.37

Report year emissions and projected emissions from BLM coal leasing authorizations are based on ONRR records of actual coal production. Table 4-2 shows a summary of the ONRR production data from states that reported federal coal production during the past 5 years. The table also shows total U.S. coal production (federal and nonfederal) to illustrate the percentage of federal coal relative to the U.S. total (% U.S. Total) and the percentage of federal coal that comes from the various federal coal producing states (% Federal). The percent total calculations are based on the 5-year average data column (see example calculation in table notes).

Table 4-2. Federal Coal Production (tons)

Area	2016	2017	2018	2019	2020	5-Year Average	% U.S. Total	% Federal
U.S. Total	728,364,498	774,609,357	756,167,095	706,309,263	534,302,000	699,950,443	100%	NA
Federal Total	296,010,202	333,532,290	308,867,606	302,347,440	246,391,712	297,429,850	42.49%	100%
WY	249,812,580	280,942,976	263,269,109	252,104,718	206,576,818	250,541,240	35.79%	84.24%
MT	13,721,842	17,187,136	16,748,966	18,067,706	13,407,510	15,826,632	2.26%	5.32%
UT	11,533,944	12,544,792	11,683,971	12,964,773	12,241,079	12,193,712	1.74%	4.1%
CO	10,351,704	10,850,837	11,263,001	10,058,177	8,987,084	10,302,161	1.47%	3.46%
ND	4,681,202	4,961,543	3,432,842	4,375,332	2,996,726	4,089,529	0.58%	1.37%
NM	5,279,407	6,289,723	1,792,186	4,214,550	1,963,242	3,907,822	0.56%	1.31%
OK	548,884	464,551	350,832	161,751	74,201	320,044	0.05%	0.11%
AL	0	76,678	207,311	399,098	145,052	165,628	0.02%	0.06%
KY	75,396	208,741	114,060	0	0	79,639	0.01%	0.03%
WA	5,243	5,313	5,328	1,335	0	3,444	0%	0%

> Ex: % U.S. Total for MT (2.26%) = (15,826,632 / 699,950,443 * 100) & % Federal MT (5.32%) = (15,826,632 / 297,429,850 * 100)

4.3 Short-Term Coal Projections

Most of the coal produced from BLM-managed lands comes from the Powder River Basin (PRB) in Wyoming and Montana. According to a recent analysis (Cohn 2021)[13], several PRB mines have closed or are scheduled to close in the next few years, and PRB production has dropped by 50% since its peak in 2010. This includes a nearly 20% decrease experienced between 2019 and 2020 as documented in Table 4-2 and in other reports (West 2021)[14]. BLM data indicates that few new coal leases have been sold in recent years, and that those leases were purchased to provide reserves for future production at existing mines. The BLM does not project any major shifts in existing coal production and does not expect any additional coal production from new leases in the next 12 months. Table 4-3 presents federal coal statistics[15] that are useful to discern leasing trends and to potentially guide future emissions estimates. The data include the number of leases, leased acres, and lease sales held for each of the past 5 years broken down by leasing region, as well as a projection of leasing statistics for 2021.

Table 4-3. Federal Coal Leasing Statistics and Projections

Area	Statistic	2016	2017	2018	2019	2020	2021 (projection)
Total Federal	Leases	301	296	298	285	283	287
	Acres	466,665	458,003	458,275	436,518	435,014	435,014
	Sales	0	2	2	2	0	0
Wyoming	Leases	102	99	99	99	99	99
	Acres	200,560	191,217	191,279	189,476	186,918	186,918

Area	Statistic	2016	2017	2018	2019	2020	2021 (projection)
	Sales	0	0	0	0	0	0
Colorado	Leases	52	51	50	49	50	50
	Acres	81,995	78,965	80,636	80,336	82,838	82,838
	Sales	0	0	0	1	0	0
Utah	Leases	72	72	71	58	58	58
	Acres	80,990	85,406	82,800	62,985	62,985	62,985
	Sales	0	1	0	0	0	0
Montana & North Dakota	Leases	48	48	52	52	52	52
	Acres	47,615	47,615	48,095	48,095	48,095	48,095
	Sales	0	1	2	0	0	0
New Mexico & Oklahoma	Leases	21	20	20	20	20	20
	Acres	42,756	42,196	42,716	42,716	41,413	41,413
	Sales	0	0	0	0	0	0
Eastern States	Leases	6	6	6	7	4	4
	Acres	12,749	12,604	12,749	12,910	12,765	12,765
	Sales	0	0	0	1	0	0

Additional Information: BLM Public Land Statistics, 2019

Based on this trend and data on leases and mine operations and closures, the BLM estimates that federal coal production will increase in 2021 but will not reach the amount produced in 2019. Projected 2021 production is therefore based on the average of 2019 and 2020 production in each state (see Table 4-2). The short-term life-of-project coal emissions for this report year are only projected for a single future year due in part to a lack of verifiable remaining coal reserve data for current leases. The BLM is also assuming that all coal produced is consumed in the same year. Projected production is presented with the emissions in Table 5-2.

4.4 Crude Oil

According to Energy Information Administration (EIA) data (2019), approximately 95% of oil stocks in the U.S. are transformed into fuels, while the remainder is refined to produce a range of petrochemical products such as plastics and other consumables. Refining processes require additional feedstocks to meet regulatory requirements or yield the desired products. Because of these feedstocks and the fact that most of the products refineries produce are less dense than the crude oil stock, refined product volume is greater than that of the crude oil feed by approximately 6.2%. This gain, known in the industry as process gain, means that the percent of crude oil stocks used to produce combustible products is essentially equivalent to the original produced crude oil volumes; and so for the purposes of this report, the BLM is assuming a 100% combustion rate for crude oil production.

To account for the methods and infrastructure used to produce and market crude oil products, this report relies on published data produced in part by the DOE NETL, which updates its 2005 well-to-wheels life-cycle GHG analysis of petroleum-based fuels consumed in the U.S. (Cooney et al. 2017).[16] The update focuses on three primary products derived from crude oil including gasoline, diesel, and jet fuel, which according to the EIA accounts for approximately 83% of the potential crude oil stock use in the U.S. To estimate crude oil life-cycle emissions from the reported production volumes, the BLM calculates a weighted average of NETL's updated modeled LCA emission factors as derived from the EIA product percentages. Table 4-4 shows the LCA emissions factors and the derived weighted fraction factors as applied in this report.

The direct emissions of methane from the oil life-cycle systems are assumed to be equivalent to the estimates used for the natural gas systems on a per unit of energy equivalent basis. This assumption is based in part on the fact that oil wells often produce associated gas along with the liquid hydrocarbons. While the associated gas itself is accounted for in the overall natural gas production data, there are known emissions points within the liquids process streams, such as tanks, components, pipelines, etc., that could leak methane dissolved within the oil. Given the inherent variability in the equipment configurations, age, and regulatory requirements applicable to the liquid hydrocarbon infrastructure in the U.S., the equivalence assumption while conservative, is reasonable for the purpose of estimating emissions in this report. Further, BLM could find no data to estimate methane emissions from the liquids alone (i.e., without the gas context). The assumption is only valid for the direct emissions portion of the life-cycle due to the different processes used to manage a liquid versus a gas in the indirect portions of the process streams. To calculate the energy equivalence of the reported crude oil production, the BLM is using published energy data from the appendix tables C-1 and C-2 of 40 CFR Part 98, Subpart C (1 barrel (bbl) of crude oil = 5,796,000 Btu = 6,016.3 megajoules (MJ)).

Table 4-4. GHG Emissions Factors for Federal Oil Production

Category	Units	CO_2e	Reference
Direct (production)	g CO_2e/MJ	13	Cooney et al. 2017
Direct (methane)	g CH_4/MJ (0.1814)	6.532	Cooney et al. 2017
Indirect (transport and distribution)	g CO_2e/MJ	1.659	Cooney et al. 2017
Indirect (refining)	g CO_2e/MJ	7.747	Cooney et al. 2017
End Use (combustion)	kg CO_2e/gal	10.326	40 CFR Part 98

g = grams, kg = kilograms, MJ = megajoule, gal = gallons.
Direct methane emissions factor is included in the direct CO_2e factor as CO_2e.

Report year emissions and projected emissions from BLM crude oil leasing authorizations and permitting actions are based on ONRR records of actual oil production. Table 4-5 shows a summary of the ONRR production data from states that reported federal oil production during the past 5 years. The table also shows total U.S. oil production (federal and nonfederal) to illustrate the percentage of federal oil relative to the U.S. total (% U.S. Total) and the percentage of federal oil that comes from the various federal oil producing states (% Federal). The U.S. total data includes all oil produced from both onshore and offshore sources. The percent total calculations are based on the 5-year average data column (see example calculation in table notes).

Table 4-5. Federal Oil Production (bbl)

Area	2016	2017	2018	2019	2020	5-Year Average	% U.S. Total	% Federal
U.S. Total	3,239,657,000	3,420,545,000	4,001,892,000	4,470,528,000	4,140,738,000	3,854,672,000	100%	NA
Federal Total	171,917,034	178,634,496	226,360,765	293,212,062	314,421,357	236,909,143	6.15%	100%
NM	74,412,963	81,854,621	117,181,306	167,815,040	197,468,433	127,746,473	3.31%	53.92%
WY	39,278,035	37,590,199	42,874,604	48,819,218	49,245,858	43,561,583	1.13%	18.39%
ND	25,857,820	28,977,899	35,125,219	45,620,848	39,263,016	34,968,960	0.91%	14.76%
CA	11,489,308	10,011,353	9,499,978	9,564,568	9,507,307	10,014,503	0.26%	4.23%
UT	9,682,409	9,144,701	8,491,520	8,225,911	6,412,327	8,391,374	0.22%	3.54%
CO	4,508,684	4,743,654	6,800,846	5,999,026	6,572,944	5,725,031	0.15%	2.42%
MT	3,111,352	2,879,130	2,983,342	3,255,779	2,900,906	3,026,102	0.08%	1.28%
AK	834,577	909,176	993,620	1,341,861	952,457	1,006,338	0.03%	0.42%
OK	970,990	652,192	582,645	798,760	627,964	726,510	0.02%	0.31%
LA	384,161	476,286	457,190	533,354	449,725	460,143	0.01%	0.19%
TX	259,898	352,632	463,375	353,852	283,556	342,663	0.01%	0.14%
MS	435,147	393,863	318,047	297,249	231,409	335,143	0.01%	0.14%
NV	273,787	281,521	254,661	264,513	237,328	262,362	0.01%	0.11%
KS	142,041	128,566	128,233	137,929	101,983	127,750	0%	0.05%
SD	125,810	114,854	114,320	105,376	98,387	111,749	0%	0.05%
AL	54,440	33,491	20,765	18,282	17,410	28,878	0%	0.01%
NE	26,412	24,890	25,405	22,695	18,477	23,576	0%	0.01%
MI	22,458	18,324	14,832	13,372	10,333	15,864	0%	0.01%
IL	16,105	16,271	11,300	7,972	8,579	12,045	0%	0.01%
OH	12,058	11,586	12,222	11,583	8,953	11,280	0%	0%
KY	7,984	6,489	5,263	4,038	3,269	5,409	0%	0%
ID	9,728	11,885	1,360	212	164	4,670	0%	0%
PA	867	912	712	624	569	737	0%	0%
AR	0	1	0	0	3	1	0%	0%

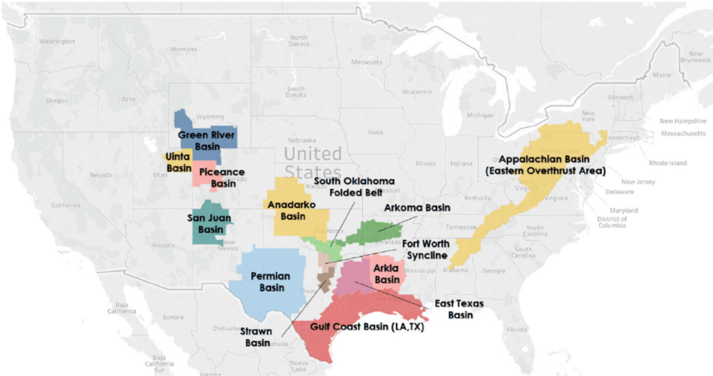
> Ex: % U.S. Total for ND (5%) = (34,968,960 / 3,854,672,000 * 100) & % Federal ND (14.76%) = (34,968,960 / 236,909,143 * 100)

4.5 Natural Gas

Natural gas is used as a combustion energy source in almost every sector of the economy. According to EIA data, approximately 3% of natural gas stocks are used in the industrial sector as a raw material to produce chemicals, fertilizer, and hydrogen. The amount of natural gas diverted into each of the noncombustion product streams is not known. However, the processes[17] that support the chemical transformation of methane (natural gas) into hydrogen is known to generate a stoichiometric amount of CO_2 emissions from the feedstock gas. Thus for this report year, the BLM is conservatively assuming that any process or product using natural gas as a feedstock would release GHGs at the same rate as combustion.

To account for the LCA emissions associated with natural gas production, the BLM is relying on data published by the Department of Energy's National Energy Technology Laboratory (DOE NETL) in a 2019 report entitled "Life Cycle Analysis of Natural Gas Extraction and Power Generation"[18]. The NETL report provides a detailed examination of the natural gas supply chain in the U.S. broken down by basin and resource type. The calculations in this report are based on the national averages published in the NETL report, as these values provide a reasonable estimation of emissions based on the fractions of production the representative federal basins contribute to total U.S. production (see Figure 4-1, which contains the applicable NETL report exhibits). The NETL report concludes that the average life-cycle GHG emissions from the U.S. natural gas supply chain are 19.9 grams (g) of carbon dioxide equivalent per megajoule (MJ) of delivered (i.e., combusted) natural gas. The report also concludes that total methane emissions throughout the supply chain are approximately 1.24% of the production volume (see Figure 4-1, NETL Exhibit 6-2). The loss of gas throughout the supply chain represents a reduction of the available gas that could be combusted by the same fraction, and so for accounting purposes the BLM is assuming a combustion rate of 98.76% of all production volumes. In terms of emissions speciation, methane alone accounts for 7.848 g CO_2e/MJ (0.218 g CH_4/MJ) of the total supply chain CO_2e factor. The BLM is assuming that 100% of the production emissions from the supply chain processes are part of the direct emissions scope from federal production. The direct emissions of CO_2 and CH_4 from the federal production supply chain are estimated to be 2.852 and 0.08 grams per megajoule, respectively. The BLM is using the published energy density of natural gas (1,026 Btu/cf) from the appendix tables C-1 and C-2 at 40 CFR Part 98, Subpart C, to calculate LCA emissions in this report.

Exhibit 2-2. Basins that Account for Majority of U.S. Natural Gas Production



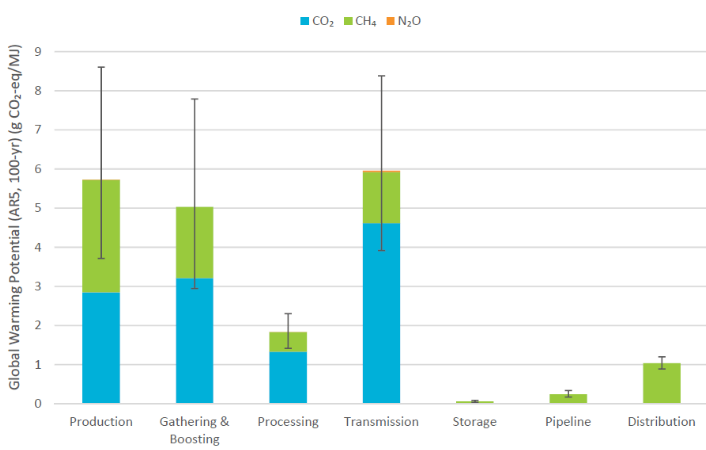
(a)

Exhibit 2-3. Natural Gas Production Shares by Well Type and Geography

Geography	Well Type						
	Conventional	Shale	Tight	CBM	Offshore	Associated	Total
Onshore Production							
Anadarko	2.2%	2.6%	1.7%				6.5%
Appalachian		29.0%					29.0%
Arkla	0.4%	4.2%	1.4%				6.0%
Arkoma	0.3%	0.9%					1.2%
East Texas	1.6%	1.3%	1.3%				4.2%
Fort Worth Syncline		1.8%	0.0%				1.8%
Green River	1.6%		3.9%				5.5%
Gulf Coast	0.8%	6.6%	1.3%				8.7%
Permian	2.3%	5.3%					7.6%
Piceance			0.3%				0.3%
San Juan	1.4%			1.9%			3.3%
South Oklahoma		1.0%					1.0%
Strawn		3.2%					3.2%
Uinta	0.5%		0.8%				1.3%
*Subtotal: Onshore**	*11.0%*	*56.0%*	*10.6%*	*1.9%*			*79.6%*
Offshore Production							
Offshore Gulf of					4.2%		4.2%
Offshore Alaska					0.1%		0.1%
Subtotal: Offshore					*4.3%*		*4.3%*
Associated Gas							
United States						16.1%	16.1%
Total							
*Total**	*11.0%*	*56.0%*	*10.6%*	*1.9%*	*4.3%*	*16.1%*	*100%*

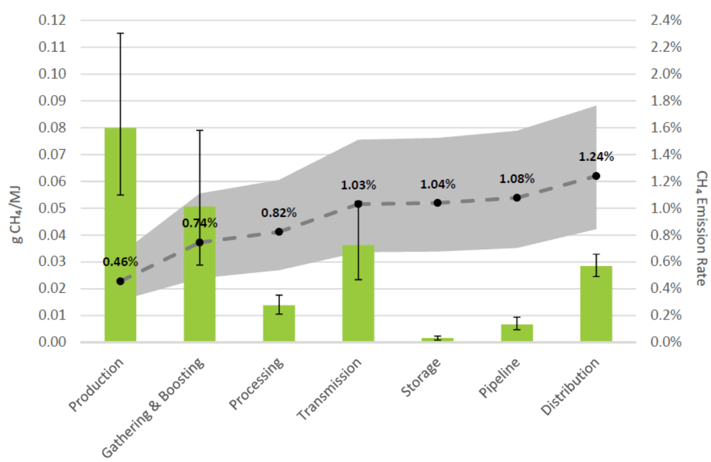
(b)

Exhibit 6-1. Life Cycle GHG Emissions for the U.S. Natural Gas Supply Chain

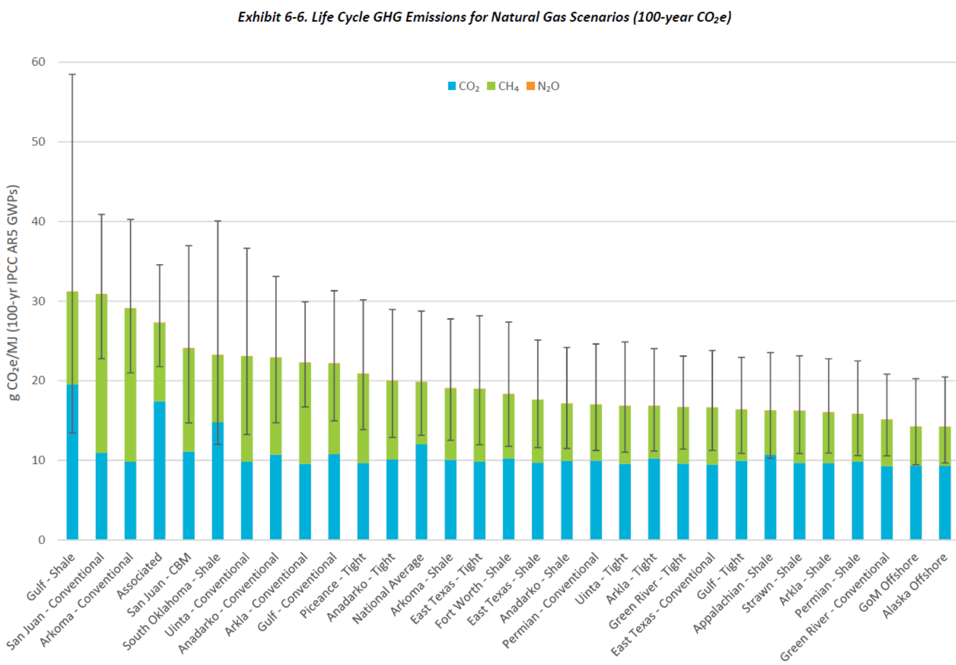


(c)

Exhibit 6-2. Life Cycle CH_4 Emissions for the U.S. Natural Gas Supply Chain



(d)



(e)

Figure 4-1. NETL Report Exhibits for LCA Estimates

Table 4-6. GHG Emissions Factors for Federal Gas Production

Category	Units	CO_2e	Reference
Direct (extraction)	g CO_2e/MJ	5.732	Cooney et al. 2019
Direct (methane)	g CH_4/MJ (0.08)	2.88	Cooney et al. 2019
Indirect (gather & boost)	g CO_2e/MJ	5.036	Cooney et al. 2019
Indirect (processing)	g CO_2e/MJ	1.854	Cooney et al. 2019
Indirect (transport & storage)	g CO_2e/MJ	7.278	Cooney et al. 2019
End Use (combustion)	kg CO_2e/scf	0.0545	40 CFR Part 98

g = grams, kg = kilograms, MJ = megajoule, gal = gallons.
Direct methane emissions factor is included in the direct CO_2e factor as CO_2e.

Report year emissions and projected emissions from BLM gas leasing authorizations and permitting actions are based on ONRR records of actual gas production. Table 4-7 shows a summary of the ONRR production data from states that reported federal gas production during the past 5 years. The table also shows total U.S. gas production (federal and nonfederal) to illustrate the percentage of federal gas relative to the U.S. total (% U.S. Total) and the percentage of federal gas that comes from the various federal gas producing states (% Federal). The U.S. total data includes all gas produced from both onshore and offshore sources. The percent total calculations are based on the 5-year average data column (see example calculation in table notes).

Table 4-7. Federal Gas Production (Mcf)

Area	2016	2017	2018	2019	2020	5-Year Average	% U.S. Total	% Federal
U.S. Total	28,400,049,000	29,237,825,000	33,008,867,000	36,515,188,000	36,172,542,000	32,666,894,200	100%	NA
Federal Total	3,300,221,597	3,236,718,007	3,327,281,643	3,386,536,791	3,293,447,433	3,308,841,094	10.13%	100%
WY	1,459,623,235	1,406,667,426	1,419,371,754	1,291,223,275	1,210,670,154	1,357,511,169	4.16%	41.03%
NM	782,795,288	786,532,574	885,024,132	1,047,716,286	1,141,952,863	928,804,229	2.84%	28.07%
CO	637,490,392	650,811,134	647,023,114	663,121,139	591,706,248	638,030,405	1.95%	19.28%
UT	235,202,222	197,763,804	175,152,176	157,320,280	139,276,421	180,942,981	0.55%	5.47%
ND	45,796,092	55,516,094	68,403,067	88,297,683	84,420,597	68,486,707	0.21%	2.07%
TX	33,291,605	31,245,879	27,612,984	27,677,111	21,409,926	28,247,501	0.09%	0.85%
LA	13,270,317	18,172,556	21,156,381	29,535,558	27,499,806	21,926,924	0.07%	0.66%
AK	14,565,324	16,345,944	14,977,468	17,782,538	17,993,335	16,332,922	0.05%	0.49%
OK	18,466,624	15,772,758	15,125,112	14,920,403	14,478,710	15,752,721	0.05%	0.48%
MT	12,846,836	12,337,060	11,695,098	11,116,341	10,442,392	11,687,545	0.04%	0.35%
AL	13,662,395	11,781,386	10,215,707	10,471,581	9,265,633	11,079,340	0.03%	0.33%
AR	12,424,517	11,001,930	10,121,088	8,943,097	8,215,842	10,141,295	0.03%	0.31%
CA	11,877,207	10,960,592	11,042,091	9,810,633	6,785,129	10,095,130	0.03%	0.31%
KS	4,223,135	3,915,997	3,761,159	3,555,465	3,224,742	3,736,100	0.01%	0.11%
OH	347,161	3,925,058	3,602,566	2,245,117	3,649,083	2,753,797	0.01%	0.08%
MI	1,368,307	1,286,369	1,198,808	1,237,833	1,104,798	1,239,223	0%	0.04%
SD	1,689,070	1,233,049	948,608	877,074	772,480	1,104,056	0%	0.03%
MS	403,612	380,157	273,389	267,817	224,962	309,987	0%	0.01%
ID	382,866	614,946	83,249	25,152	11,465	223,536	0%	0.01%
VA	156,876	148,092	138,262	123,196	116,552	136,596	0%	0%
KY	156,228	122,040	112,145	106,260	97,191	118,773	0%	0%
WV	137,852	138,197	119,371	82,685	56,494	106,920	0%	0%
PA	26,713	28,755	110,760	68,498	54,450	57,835	0%	0%
NY	6,042	7,647	7,797	7,559	5,722	6,953	0%	0%
IL	9,233	6,532	3,638	2,584	2,196	4,837	0%	0%
NV	1,813	1,772	1,708	1,617	10,240	3,430	0%	0%
NE	635	259	11	9	2	183	0%	0%

Ex: % U.S. Total for CO (1.95%) = (638,030,405 / 32,666,894,200 * 100) & % Federal CO (19.28%) = (638,030,405 / 3,308,841,094 * 100)

4.6 Short-Term Oil and Gas Projections

The short-term projections for oil and gas emissions are based on analyses of three authorization scopes that exist for potential oil and gas production. These include (1) leased federal lands that are held-by-production, (2) approved applications for permit to drill (APDs), and (3) leased lands from competitive lease sales expected to occur over the next annual reporting cycle (12 months). As was the case for coal, here too the BLM is assuming that all oil and gas developed is consumed in the same year. When initiating a planning action in an area of potential oil and gas development, the BLM may produce an analysis of the fluid mineral potential known as a Reasonably Foreseeable Development Scenario (RFD) for oil and gas development for the specific geographic area. An RFD is typically constructed to support the management actions developed for a field or district office's resource management plan. The RFD provides an estimate of development potential and growth rates within the specified region based on several indicators, including the estimated hydrocarbon potential, operator surveys, existing development trends, various economics forecasts, and basin or geology factors, among others. These documents typically provide 20+ years of oil and gas development estimates and have traditionally been used to inform decisions on areas open and closed for leasing and the need for implementing stipulations, conditions of approval, or mitigation measures. The RFDs that are currently available, although useful for informing management actions and tracking limits of analysis for a particular region, are not useful for estimating GHG emissions across all BLM-managed mineral estate in a particular year because of their differing years of analysis, projection methodologies, and management objectives. The BLM does not currently have an up-to-date RFD that covers the entire federal onshore mineral estate. Due to the inconsistencies among available RFDs and a lack of an RFD for all federal mineral producing regions, the individual RFDs or a summation of all available RFDs may not be used to derive a single replicable methodology from which to make projections, which is one of the goals of this report. Thus, for the purposes of this report, a more representative and consistent approach for making projections that captures the implications of different levels of development and production across the entirety of the federal mineral estate was employed.

Each of the authorization scopes previously described relies in part on the most recent 5-year average dataset of federal mineral statistics[19] developed by the BLM in combination with the previously identified external sources of fossil fuel production data. The development statistics include both internal BLM tracking data, such as annual lease acres and held-by-production rates, APD approval counts, spud rates, and producible well counts, as well as an analysis of external well completion and production rates for individual wells in states reporting federal oil and gas production. Additional parameters are calculated from the internal statistics to aid in the projection calculations and to provide custom metrics for tracking purposes as shown in Table 4-8.

Table 4-8. 5-Year Federal Oil and Gas Statistics (BLM Totals)

Statistic	2016	2017	2018	2019	2020	5-Year Average
Acres Under Lease	27,207,018	25,742,991	25,552,475	26,287,326	26,604,169	26,278,796
Producing Acres	12,771,830	12,790,557	12,794,552	12,915,006	12,711,111	12,796,611
Acres Held by Production (%) *	46.94%	49.69%	50.07%	49.13%	47.78%	48.7%
New Lease Acres (sold)	577,317	1,114,218	1,253,369	2,245,906	1,871,962	1,412,553
Number of APDs Approved	2,184	2,486	3,388	3,181	4,226	3,928

Statistic	2016	2017	2018	2019	2020	5-Year Average
Number of Wells Spud	847	1,428	1,919	1,995	1,486	1,533
Number of Producible Wells	94,096	94,434	96,199	96,356	96,110	95,437
Federal Wells per Acre *	0.245	0.312	0.3215	0.3119	0.3131	0.3007
Total Potential Wells *	189,524	181,534	185,671	186,699	192,262	187,136
Potential New Wells *	95,441	87,112	89,485	90,356	96,165	91,711
Potential Development Years *	4,473.3	1,764	608.9	1,172.7	1,090	1,823
Total CO2e Emissions (Mt) *	252.21	251.71	277.3	309.45	313.64	280.86
CO2e Emissions (tonnes/prod acre) *	418.92	421.03	404.8	439.91	407.76	418.5
Potential New Lease Wells *	1,479	1,611	3,102	6,294	2,897	3,133

Source: BLM Oil and Gas Statistics.
"*" Denotes calculated parameter.

The BLM analyzed 10 years (2011-2020) of external data from the IHS Markit Enerdeq database (commercial source) for oil and gas wells in federal mineral producing states. The analysis of the individual wells provided an estimate of the total potential mineral yield, or estimated ultimate recovery (EUR), and the associated decline rates that could be expected from any new wells developed within the authorization scopes analyzed in this report. Producing the EUR and decline estimates was necessary because life-of-project production is a reasonably foreseeable outcome from existing and future authorizations if economic quantities of federal minerals exist within any authorization scope.

Enerdeq provides subscription-based access to more than 5 million completions and 2.5 million production entities and provides an adequate sample size for most regions to apply statistical methods for determining the EUR. Initially, the BLM made queries to obtain the American Petroleum Institute (API) well identifiers for all new wells completed within the last 10 years. The 10-year timeframe was chosen to capture the changes in characteristics for wells developed before and after the advent and widespread adoption of horizontal drilling and hydraulic fracturing completion techniques. The queried data was scrubbed to eliminate nontarget wells (e.g., injection, water) and then organized by state to query 10 years of production data. This query provided the individual well production-by-age data that was necessary to develop the decline curve profiles and provide for cumulative production estimates over the life of a well. Oil and gas wells typically produce high quantities of minerals initially, followed by a period of rapid decline that settles into a very shallow decline over the remainder of their economic life. The BLM applied regression analysis techniques to the production data to generate a typical decline equation for wells in each state. The EUR for each state was calculated for an estimated life span of 30 years. These EUR volumes were then applied to the estimated number of new wells projected for the applicable authorization boundaries in each state to estimate cumulative or life-of-project GHG emissions. The decline curve formulas are also useful for estimating existing held-by-production projections as described later. Table 4-9 presents some of the IHS data highlights that went into the BLM's analysis, and Figure 4-2 shows the results of the decline analysis for the selected state.

Table 4-9. IHS Markit Enerdeq Data as Analyzed by BLM

State	New Well Count	Dev Status	Vertical	Horizontal	Percent Oil Prod	Oil Prod Record Cnt	Percent Gas Prod	Gas Prod Record Cnt	No. of Basin / Formations
AK	1,429		226	1,203	2.11%	588	2.85%	655	2
AL	775		753	23	0.15%	175	0.06%	503	4
AR	4,628		1,725	2,903	0.05%	270	2.48%	3,167	2
CA	16,815	Active	14,807	2,008	0.19%	1,315	0.03%	1,062	5
CO	18,560	Active	9,487	9,073	5.16%	17,055	4.75%	17,798	15
ID	11		11	0	0.00%	0	0.00%	0	1
KS	15,786	Active	15,395	391	0.53%	3,916	0.15%	1,215	12
LA	10,304	Active	6,873	3,431	3.05%	3,711	11.16%	4,557	1
MI	368		217	151	0.09%	188	0.02%	97	2
MS	1,319		1,220	99	0.38%	690	0.05%	316	3
MT	1,241		421	820	0.45%	788	0.05%	757	14
ND	16,035	Active	123	15,912	16.01%	13,890	2.73%	13,855	1
NE	479		477	2	0.04%	254	0.00%	1	6
NM	11,482	Active	4,610	6,872	7.08%	9,811	2.70%	10,043	6
NV	6		6	0	0.00%	0	0.00%	0	1
NY	986		973	13	0.00%	838	0.00%	790	1
OH	4,091		1,337	2,754	0.72%	2,807	6.13%	3,697	2
OK	20,081	Active	7,158	12,923	5.07%	13,408	6.97%	14,245	14
OR	4		4	0	0.00%	0	0.00%	0	1
PA	13,971	Active	4,629	9,342	0.21%	5,396	21.80%	12,959	2
SD	65		5	60	0.02%	44	0.00%	31	4
TX	107,473	Active	49,715	57,758	55.24%	46,383	28.48%	47,330	15
UT	6,217		5,851	366	0.99%	4,672	0.81%	4,672	10
WV	3,877		845	3,032	0.42%	2,720	5.75%	3,663	1
WY	9,975	Active	7,564	2,411	2.04%	7,038	3.02%	7,234	13
Totals	**265,978**		**134,432**	**131,547**	**100%**	**135,957**	**100%**	**148,647**	**138**

Data is representative of all wells (federal and nonfederal) drilled and producing within the analyzed period.
Active status assigned to states with development rates of approximately 1,000 or more wells per year.

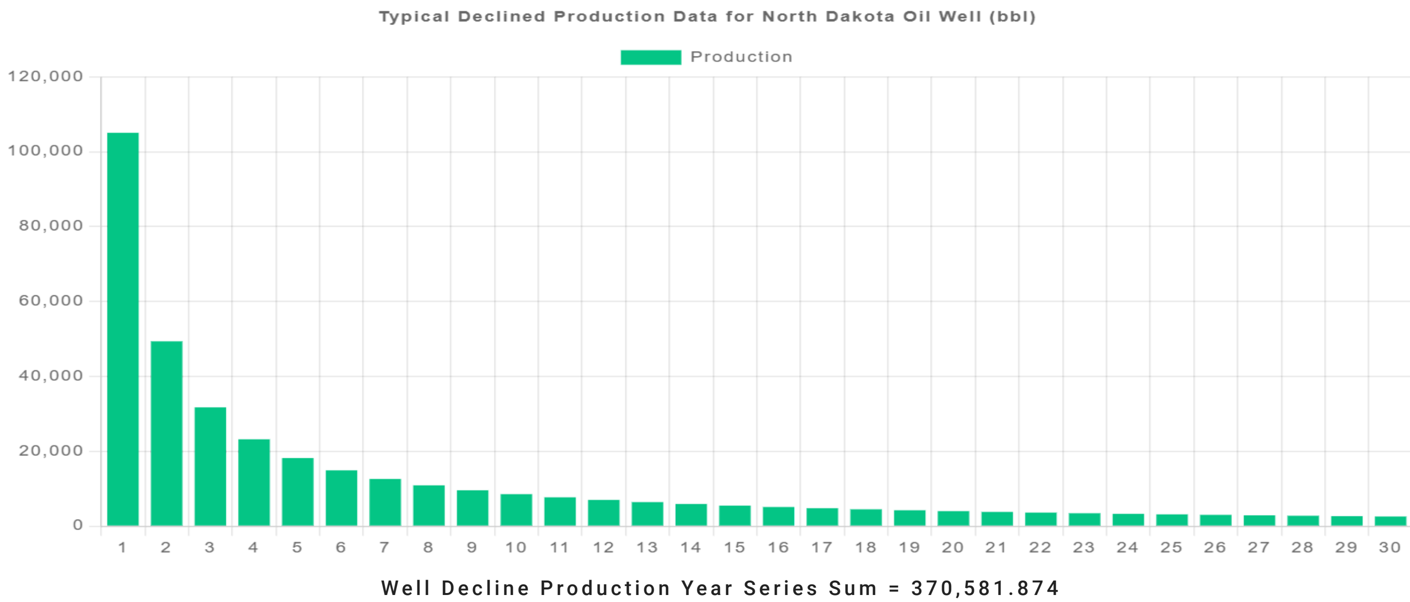


Figure 4-2. State Oil and Gas Decline Curves (North Dakota - Oil)

Leased Lands

To estimate the potential GHG emissions resulting from leased lands held-by-production, the BLM applies the derived decline curves on a relative basis to the report year production levels and projects out for an additional 30 years (the assumed life-of-project period) for each applicable state. The decline curves for any state are statistically valid for an average "new" well; however, the held-by-production data is representative of wells at various ages. Thus applying the decline curve to existing field-wide production would most likely underrepresent future cumulative emissions. The decline data show that newer wells are far more productive in their first few years of life than over the entire life of the project period, and thus it is generally assumed that for any region with active development, the newer wells are driving production. For these areas, the BLM assumed a field-wide decline age of 5 years. For a majority of the decline data, the 5-year mark lands squarely at the heel of the harmonic shaped curves (see Figure 4-2, year 5) and should correspond with a moderate gradual decline that could be expected at field-wide scales with active development. For all other regions, the decline age was assumed to be 10 years (very shallow decline, leading to sustained production over the projection period). Additionally, this analysis conservatively assumes that all existing wells on leases held-by-production will continue to produce for another 30 years, even though it is highly likely that some will be plugged and abandoned. This fact can be clearly seen in the data contained in Table 4-8; even though the BLM recorded 1,533 well spuds per year on average over the 5-year period, the producible well counts only increased by 2,014 wells over the entire 5-year period. Its likely that some of the recorded spuds came up dry leading to a smaller increment in the producible well counts, just as it is likely that some of the producible wells on record reached the end of their economic lives (i.e., no longer considered producible), and were thus subtracted from this count.

Approved Applications for Permit to Drill

To estimate the potential GHG emissions resulting from approved APDs, the BLM uses the last 2 years of approved APD counts minus the spuds recorded for the same period. Here the BLM is breaking from the general approach in this report of using 5-year average data for making projections in acknowledgement that APDs are only valid for 2 years (absent extensions that can be granted for an additional 2 years with appropriate justification). In general, the BLM statistics show that spud counts lag APD approvals across the states, and therefore it is reasonable to assume that the delta between the two metrics is enough to cover any potential extensions and subsequent development that may arise during the reporting period (i.e., the next 12 months). The remaining APD counts are multiplied by the corresponding decline curve equation that was derived for each state.

Potential Future Leasing

Estimates of potential GHG emissions resulting from any future leasing are relatively speculative. In terms of emissions, the BLM is assuming that full development of the leased parcels would occur concurrently within the same sale (report) year. While this assumption does not reflect a typical timeline for oil and gas development, it is simplifying for projection purposes and allows the BLM to evaluate the potential emissions for any authorizations made. Here, the BLM relies on the 5-year average of the acres held by production, the annual total leased acres, and the calculated well density (wells per acre) on the federal mineral estate. Additionally, for some states with leased lands where the 5-year average statistics fall below a threshold minimum, the BLM assumes a minimum leased acreage to conservatively estimate potential emissions. The minimum thresholds are 100 acres leased for states with less than 4,000 acres currently leased, and 2,560 acres leased for states with more than 4,000 acres currently leased for which the 5-year leasing average is less than the minimum itself. The statistical annual lease acres data (5-year average) or the alternative minimum lease acres is used to estimate the number of wells for potentially leased lands which are then multiplied by the corresponding decline curve data for each state to obtain the estimated life-of-project production and emissions.

4.7 Long-Term Federal Fossil Fuel Mineral Emissions Projections

The emission estimates from the federal mineral estate authorization boundaries previously outlined present current emissions and projected emissions based on potential development and production volumes over the short term. As discussed at the beginning of this section, the BLM is using data from EIA's AEO report to estimate potential long-term emissions (to year 2050). The AEO is developed using the National Energy Modeling System (NEMS), an integrated model that captures interactions of economic changes and energy supply, demand, and prices. The AEO is published to satisfy the Department of Energy Organization Act of 1977, which requires EIA's Administrator to prepare annual reports on trends and projections for energy use and supply. The AEO explores several scenarios that capture alternative policy-based cases that can be compared to the reference case, which represents EIA's best assessment of how U.S. and world energy markets will operate through 2050. The reference case examines a future characterized by slower growth in energy consumption (due to energy efficiency increases) and by increasing energy supply due to technological progress in the renewable, oil, and natural gas energy sectors. The reference case is also the baseline scenario from which all other side-case estimates are made. The most current version of the report (AEO 2021) was used to supplement this report. **Note:** Projections in the AEO are not predictions of what will happen, but rather, they are modeled projections of what may happen given certain assumptions. The major underlying assumption for the application of any AEO scenario data is that the ratio of federal and nonfederal mineral production is fixed at the current 5-year average for each state going forward. The five-year average was chosen to alleviate any annual variability in production that can arise for any number of reasons. For each year of AEO data, which is inclusive of total (federal and nonfederal) production, the BLM is applying the 5-year average federal fraction for each mineral type to forecast long-term federal mineral production from which to estimate emissions. Overall, this forecast method is useful for analyzing long-term trends in GHG emissions and comparing the levels to specific climate change policy milestones to ascertain reasonable progress.

4.8 Uncertainties in Emissions Estimates

This report relies on life-cycle emissions estimates produced in part by the DOE NETL (as previously cited). The life-cycle estimates produced by the BLM cover broad activities used to represent recovery and processing of federal minerals, including lease exploration, construction, well drilling and completion, production, processing, transportation, and end use. The BLM acknowledges that operational diversity, product variations, and broad geographic distribution of the federal mineral estate introduces some uncertainty into the simplifying assumptions and approximation methodologies used to estimate emissions in this report. This acknowledgement is not intended to dispute the validity of the estimates but to help prioritize efforts to improve the accuracy of future iterations of this report. For some of the current estimates, such as CO_2 emissions from energy-related combustion activities, the impact of uncertainties on overall emission estimates is believed to be relatively small. For some other limited categories of emissions, including the assumptions used to estimate production and project future emissions, the following uncertainties could have a larger impact on the estimates.

- The uncertainties inherent to the sourced LCA data, which is unavoidably propagated in the BLM estimates.
- Uncertainty in global warming potential (GWP) factors, which may be up to + or - 40% and may change often due to updated scientific understanding.
- Unknowable factors about actual or future development localities, methodologies, and production rates.
- The exact nature of energy sources and amounts used in production, transportation, and processing systems.
- How the produced federal minerals are ultimately transformed and used.
- The overall energy density of the produced federal mineral estate (used in emissions calculations).
- The exact nature of any control technology that may be utilized at direct or indirect activity locations.
- Regulatory and policy posture changes with respect to GHGs by governments or agencies with authority for such matters

The BLM is making a broad but concerted effort to utilize and present the best data available for the emissions estimates in this report. As new information becomes available, the BLM will continue to improve and revise its emission estimates, methodologies, and assumptions as appropriate. Ultimately, these estimates are subject to many influences that are largely beyond the BLM's practical control. Unforeseen changes in several factors such as geologic conditions, drilling technology, global and national economics, energy demand, and laws and policies enacted at the federal, state, and local level could result in different outcomes than those projected in this assessment.

* * *

5.0 GHG Emissions and Projections from BLM-Authorized Actions

This chapter provides direct and indirect GHG emission estimates for both existing and projected federal fossil fuel production. Existing emissions estimates show the GHGs emitted from the assumed consumption of each fossil fuel based on production statistics from the previous fiscal year for all producing wells and mines. The projected emissions include both, short- and long-term estimates based on the methodologies discussed in the previous chapter.

5.1 Short-Term Coal Emissions

Table 5-1 presents the emissions from coal production on the federal mineral estate in FY 2020, which result from multiplying the representative emission factors from Table 4-1 by the state-specific production amounts from Table 4-2. The estimates presented here include emissions from the typical coal lifecycle, including emissions arising from activities outside of the BLM's jurisdiction (such as emissions associated with coal exports). Table 5-2 shows the short-term emissions projections from reasonably foreseeable coal production in the 8 states where the BLM has currently authorized coal leasing.

Table 5-1. Federal Coal Emissions - 2020 (Mt)

Area	2020 Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
U.S. Total	534,302,000	0.8442	33.116	NA	28.7187	1,186.24	1,248.07
Federal Total	246,391,712	0.0588	4.846	NA	27.3627	458.74	490.94
WY	206,576,818	0.0303	3.0739	NA	24.4009	366.31	393.78
MT	13,407,510	0.002	0.1995	NA	1.5837	23.77	25.55
UT	12,241,079	0.0119	0.3192	NA	0.5136	30.63	31.46
CO	8,987,084	0.0142	0.557	NA	0.4831	27.88	28.92
ND	2,996,726	0.0004	0.0446	NA	0.354	5.31	5.71
NM	1,963,242	0	0.5863	NA	0.0247	4.36	4.97
AL	145,052	0	0.0433	NA	0.0018	0.32	0.37
OK	74,201	0	0.0222	NA	0.0009	0.16	0.18

Production units = tons.
LCA CH_4 is included in the Extraction CO_2e estimates as CO_2e.
U.S. Total is both federal and nonfederal data, shown for illustration purposes.

Table 5-2. Federal Coal Emissions - Projected Short-Term Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	274,368,909	0.2955	5.6593	0	30.4683	509.92	546.06
WY	229,340,768	0.0336	3.4126	NA	27.0897	406.6739	437.18
MT	15,737,608	0.2342	0.2342	NA	1.8589	27.9064	30
UT	12,602,926	0.0122	0.3287	NA	0.5288	31.5384	32.4
CO	9,522,631	0.015	0.5902	NA	0.5118	29.5385	30.64
ND	3,686,029	0.0005	0.0548	NA	0.4354	6.5362	7.03
NM	3,088,896	0	0.9224	NA	0.0388	6.8579	7.82
AL	272,075	0	0.0812	NA	0.0034	0.6041	0.69
OK	117,976	0	0.0352	NA	0.0015	0.2619	0.3

> EUR means Estimated Ultimate Recovery (production), units are short tons.
> LCA CH_4 is included in the Extraction CO_2e estimates as $CO2_2e$.
> Emissions are projected for a single future year due to a lack of verifiable remaining coal reserve data.

5.2 Short-Term Oil and Gas Emissions

Tables 5-3 and 5-6 present the short-term LCA emissions from oil and gas production on the federal mineral estate in FY 2020 (held-by-production), which result from multiplying the representative emission factors from Tables 4-4 and 4-6 by the state-specific production amounts from Tables 4-5 and 4-7, respectively. The estimates presented here include emissions from the full oil and gas lifecycle, including emissions arising from activities outside of the BLM's jurisdiction (such as emissions associated with refining and processing). Tables 5-4, 5-5, 5-7, and 5-8 show the short-term LCA emissions projections from reasonably foreseeable oil and gas production on the held-by-production lands for the next twelve months and over the estimated life-of-project.

Table 5-3. Federal Oil Emissions - Held-By-Production Lands 2020 (Mt)

Area	2020 Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
U.S. Total	4,140,738,000	5.52	329.1736	196.1618	42.0085	1,795.82	2,363.16
Federal Total	314,421,357	0.3489	24.9954	14.8953	3.1899	136.36	179.44
NM	197,468,433	0.2191	15.698	9.3548	2.0034	85.64	112.7
WY	49,245,858	0.0546	3.9149	2.333	0.4996	21.36	28.11
ND	39,263,016	0.0436	3.1213	1.86	0.3983	17.03	22.41
CA	9,507,307	0.0105	0.7558	0.4504	0.0965	4.12	5.42
CO	6,572,944	0.0073	0.5225	0.3114	0.0667	2.85	3.75
UT	6,412,327	0.0071	0.5098	0.3038	0.0651	2.78	3.66
MT	2,900,906	0.0032	0.2306	0.1374	0.0294	1.26	1.66
AK	952,457	0.0011	0.0757	0.0451	0.0097	0.41	0.54
OK	627,964	0.0007	0.0499	0.0297	0.0064	0.27	0.36
LA	449,725	0.0005	0.0358	0.0213	0.0046	0.2	0.26
TX	283,556	0.0003	0.0225	0.0134	0.0029	0.12	0.16
NV	237,328	0.0003	0.0189	0.0112	0.0024	0.1	0.13
MS	231,409	0.0003	0.0184	0.011	0.0023	0.1	0.13
KS	101,983	0.0001	0.0081	0.0048	0.001	0.04	0.05
SD	98,387	0.0001	0.0078	0.0047	0.001	0.04	0.05
NE	18,477	0	0.0015	0.0009	0.0002	0.01	0.01
AL	17,410	0	0.0014	0.0008	0.0002	0.01	0.01
MI	10,333	0	0.0008	0.0005	0.0001	0	0
OH	8,953	0	0.0007	0.0004	0.0001	0	0
IL	8,579	0	0.0007	0.0004	0.0001	0	0
KY	3,269	0	0.0003	0.0002	0	0	0
PA	569	0	0	0	0	0	0
ID	164	0	0	0	0	0	0
AR	3	0	0	0	0	0	0

> Production units (bbl).
> U.S. Total is both federal and nonfederal data, shown for illustration purposes.

Table 5-4. Federal Oil Emissions - Held-By-Production Lands Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	238,642,669	0.2647	18.9714	11.3055	2.4213	103.48	136.18
NM	145,466,545	0.1614	11.5641	6.8913	1.4758	63.09	83.02
ND	32,188,451	0.0357	2.5589	1.5249	0.3266	13.96	18.37
WY	37,946,927	0.0421	3.0166	1.7977	0.385	16.46	21.66
CA	7,758,321	0.0086	0.6168	0.3675	0.0787	3.36	4.42
UT	5,122,593	0.0057	0.4072	0.2427	0.052	2.22	2.92
MT	2,668,212	0.003	0.2121	0.1264	0.0271	1.16	1.53
CO	4,662,063	0.0052	0.3706	0.2209	0.0473	2.02	2.66
AK	898,844	0.001	0.0715	0.0426	0.0091	0.39	0.51
OK	568,214	0.0006	0.0452	0.0269	0.0058	0.25	0.33
LA	423,350	0.0005	0.0337	0.0201	0.0043	0.18	0.24
TX	262,376	0.0003	0.0209	0.0124	0.0027	0.11	0.15
MS	215,097	0.0002	0.0171	0.0102	0.0022	0.09	0.12
NV	213,400	0.0002	0.017	0.0101	0.0022	0.09	0.12
SD	92,748	0.0001	0.0074	0.0044	0.0009	0.04	0.05
KS	93,303	0.0001	0.0074	0.0044	0.0009	0.04	0.05
NE	17,134	0	0.0014	0.0008	0.0002	0.01	0.01
AL	16,247	0	0.0013	0.0008	0.0002	0.01	0.01
MI	9,650	0	0.0008	0.0005	0.0001	0	0
IL	8,012	0	0.0006	0.0004	0.0001	0	0
OH	7,626	0	0.0006	0.0004	0.0001	0	0
KY	2,898	0	0.0002	0.0001	0	0	0
PA	504	0	0	0	0	0	0
ID	151	0	0	0	0	0	0
AR	3	0	0	0	0	0	0

Production units (bbl).

Table 5-5. Federal Oil Emissions - Held-By-Production Lands Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	1,860,945,007	2.0648	147.94	88.16	18.88	807.09	1,062.08
NM	978,834,961	1.086	77.8138	46.371	9.9305	424.52	558.64
ND	333,952,435	0.3705	26.548	15.8205	3.388	144.83	190.59
WY	302,793,218	0.336	24.071	14.3444	3.0719	131.32	172.81
CA	78,842,196	0.0875	6.2677	3.735	0.7999	34.19	44.99
UT	47,435,886	0.0526	3.771	2.2472	0.4812	20.57	27.07
MT	42,837,144	0.0475	3.4054	2.0294	0.4346	18.58	24.45
CO	27,521,847	0.0305	2.1879	1.3038	0.2792	11.94	15.71
AK	17,275,101	0.0192	1.3733	0.8184	0.1753	7.49	9.86
OK	8,180,577	0.0091	0.6503	0.3875	0.083	3.55	4.67
LA	7,991,271	0.0089	0.6353	0.3786	0.0811	3.47	4.57
TX	4,388,383	0.0049	0.3489	0.2079	0.0445	1.9	2.5
MS	3,712,495	0.0041	0.2951	0.1759	0.0377	1.61	2.12
NV	2,949,851	0.0033	0.2345	0.1397	0.0299	1.28	1.68
SD	1,768,578	0.002	0.1406	0.0838	0.0179	0.77	1.01
KS	1,444,897	0.0016	0.1149	0.0685	0.0147	0.63	0.83
NE	290,965	0.0003	0.0231	0.0138	0.003	0.13	0.17
AL	288,360	0.0003	0.0229	0.0137	0.0029	0.13	0.17
MI	172,119	0.0002	0.0137	0.0082	0.0017	0.07	0.09
IL	142,902	0.0002	0.0114	0.0068	0.0014	0.06	0.08
OH	76,320	0.0001	0.0061	0.0036	0.0008	0.03	0.04
KY	36,651	0	0.0029	0.0017	0.0004	0.02	0.03
PA	6,379	0	0.0005	0.0003	0.0001	0	0
ID	2,422	0	0.0002	0.0001	0	0	0
AR	49	0	0	0	0	0	0

EUR Production units (bbl).

Table 5-6. Federal Gas Emissions - Held-By-Production Lands 2020 (Mt)

Area	2020 Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
U.S. Total	36,172,542,000	3.1325	224.444	72.5958	482.1709	1,947.21	2,726.42
Federal Total	3,293,447,433	0.2852	20.4352	6.6097	43.9008	177.29	248.24
WY	1,210,670,154	0.1048	7.512	2.4297	16.1379	65.17	91.25
NM	1,141,952,863	0.0989	7.0856	2.2918	15.2219	61.47	86.07
CO	591,706,248	0.0512	3.6714	1.1875	7.8873	31.85	44.6
UT	139,276,421	0.0121	0.8642	0.2795	1.8565	7.5	10.5
ND	84,420,597	0.0073	0.5238	0.1694	1.1253	4.54	6.36
LA	27,499,806	0.0024	0.1706	0.0552	0.3666	1.48	2.07
TX	21,409,926	0.0019	0.1328	0.043	0.2854	1.15	1.61
AK	17,993,335	0.0016	0.1116	0.0361	0.2398	0.97	1.36
OK	14,478,710	0.0013	0.0898	0.0291	0.193	0.78	1.09
MT	10,442,392	0.0009	0.0648	0.021	0.1392	0.56	0.79
AL	9,265,633	0.0008	0.0575	0.0186	0.1235	0.5	0.7
AR	8,215,842	0.0007	0.051	0.0165	0.1095	0.44	0.62
CA	6,785,129	0.0006	0.0421	0.0136	0.0904	0.37	0.52
OH	3,649,083	0.0003	0.0226	0.0073	0.0486	0.2	0.28
KS	3,224,742	0.0003	0.02	0.0065	0.043	0.17	0.24
MI	1,104,798	0.0001	0.0069	0.0022	0.0147	0.06	0.08
SD	772,480	0.0001	0.0048	0.0016	0.0103	0.04	0.06
MS	224,962	0	0.0014	0.0005	0.003	0.01	0.01
VA	116,552	0	0.0007	0.0002	0.0016	0.01	0.01
KY	97,191	0	0.0006	0.0002	0.0013	0.01	0.01
WV	56,494	0	0.0004	0.0001	0.0008	0	0
PA	54,450	0	0.0003	0.0001	0.0007	0	0
ID	11,465	0	0.0001	0	0.0002	0	0
NV	10,240	0	0.0001	0	0.0001	0	0
NY	5,722	0	0	0	0.0001	0	0
IL	2,196	0	0	0	0	0	0
NE	2	0	0	0	0	0	0

> Production units (Mcf).
> U.S. Total is both federal and nonfederal data, shown for illustration purposes.

Table 5-7. Federal Gas Emissions - Held-By-Production Lands Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	2,664,011,775	0.2306	16.5296	5.3463	35.5107	143.4	200.79
WY	1,029,379,035	0.0891	6.3871	2.0659	13.7214	55.41	77.58
NM	908,057,421	0.0786	5.6343	1.8224	12.1042	48.88	68.44
CO	423,053,787	0.0366	2.625	0.849	5.6392	22.77	31.88
UT	120,684,134	0.0105	0.7488	0.2422	1.6087	6.5	9.1
ND	68,883,035	0.006	0.4274	0.1382	0.9182	3.71	5.19
LA	24,647,247	0.0021	0.1529	0.0495	0.3285	1.33	1.86
TX	19,594,579	0.0017	0.1216	0.0393	0.2612	1.05	1.47
AK	16,540,344	0.0014	0.1026	0.0332	0.2205	0.89	1.25
OK	13,207,446	0.0011	0.0819	0.0265	0.1761	0.71	0.99
MT	9,690,823	0.0008	0.0601	0.0194	0.1292	0.52	0.73
AL	8,566,139	0.0007	0.0532	0.0172	0.1142	0.46	0.64
AR	7,593,998	0.0007	0.0471	0.0152	0.1012	0.41	0.57
CA	5,704,256	0.0005	0.0354	0.0114	0.076	0.31	0.43
KS	2,931,628	0.0003	0.0182	0.0059	0.0391	0.16	0.22
OH	3,134,597	0.0003	0.0194	0.0063	0.0418	0.17	0.24
MI	1,076,544	0.0001	0.0067	0.0022	0.0144	0.06	0.08
SD	729,876	0.0001	0.0045	0.0015	0.0097	0.04	0.06
MS	211,481	0	0.0013	0.0004	0.0028	0.01	0.01
VA	107,753	0	0.0007	0.0002	0.0014	0.01	0.01
KY	89,854	0	0.0006	0.0002	0.0012	0	0
PA	49,231	0	0.0003	0.0001	0.0007	0	0
WV	50,781	0	0.0003	0.0001	0.0007	0	0
ID	10,640	0	0.0001	0	0.0001	0	0
NY	5,652	0	0	0	0.0001	0	0
NV	9,352	0	0.0001	0	0.0001	0	0
IL	2,140	0	0	0	0	0	0
NE	2	0	0	0	0	0	0

Production units (Mcf).

Table 5-8. Federal Gas Emissions - Held-By-Production Lands Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	27,524,613,884	2.3835	170.79	55.24	366.9	1,481.69	2,074.62
WY	12,657,678,353	1.0961	78.5386	25.4031	168.7237	681.38	954.05
NM	8,244,637,251	0.714	51.1565	16.5464	109.8989	443.82	621.42
CO	2,565,021,869	0.2221	15.9155	5.1478	34.1911	138.08	193.33
UT	1,628,264,872	0.141	10.1031	3.2678	21.7044	87.65	122.73
ND	699,674,711	0.0606	4.3414	1.4042	9.3265	37.66	52.73
LA	333,721,886	0.0289	2.0707	0.6698	4.4484	17.96	25.15
TX	304,167,512	0.0263	1.8873	0.6104	4.0545	16.37	22.92
AK	264,497,978	0.0229	1.6412	0.5308	3.5257	14.24	19.94
OK	200,552,168	0.0174	1.2444	0.4025	2.6733	10.8	15.12
MT	165,411,686	0.0143	1.0263	0.332	2.2049	8.9	12.46
AL	142,424,382	0.0123	0.8837	0.2858	1.8985	7.67	10.74
AR	126,078,110	0.0109	0.7823	0.253	1.6806	6.79	9.51
CA	66,460,780	0.0058	0.4124	0.1334	0.8859	3.58	5.01
KS	43,525,338	0.0038	0.2701	0.0874	0.5802	2.34	3.28
OH	32,880,605	0.0028	0.204	0.066	0.4383	1.77	2.48
MI	26,291,059	0.0023	0.1631	0.0528	0.3505	1.42	1.99
SD	14,150,340	0.0012	0.0878	0.0284	0.1886	0.76	1.06
MS	3,953,332	0.0003	0.0245	0.0079	0.0527	0.21	0.3
VA	1,791,550	0.0002	0.0111	0.0036	0.0239	0.1	0.14
KY	1,493,947	0.0001	0.0093	0.003	0.0199	0.08	0.11
PA	705,183	0.0001	0.0044	0.0014	0.0094	0.04	0.06
WV	700,411	0.0001	0.0043	0.0014	0.0093	0.04	0.06
ID	181,610	0	0.0011	0.0004	0.0024	0.01	0.01
NY	153,523	0	0.001	0.0003	0.002	0.01	0.01
NV	143,138	0	0.0009	0.0003	0.0019	0.01	0.01
IL	52,259	0	0.0003	0.0001	0.0007	0	0
NE	31	0	0	0	0	0	0

EUR Production units (Mcf).

Tables 5-9 through and 5-12 present the short-term projections of LCA emissions for reasonably foreseeable oil and gas production from approved APDs. The estimates shown assume all APDs will be drilled, completed, and have completed a full 12 months of production during the next 12 months.

Table 5-9. Federal Oil Emissions - Approved APDs Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	302,497,744	0.3356	24.04	14.32	3.07	131.18	172.61
NM	243,111,694	0.2697	19.33	11.52	2.47	105.44	138.76
WY	28,403,578	0.0315	2.26	1.35	0.29	12.32	16.22
ND	9,140,391	0.0101	0.73	0.43	0.09	3.96	5.21
CO	10,752,794	0.0119	0.85	0.51	0.11	4.66	6.13
AK	2,221,909	0.0025	0.18	0.11	0.02	0.96	1.27
CA	3,745,574	0.0042	0.3	0.18	0.04	1.62	2.14
UT	3,455,097	0.0038	0.27	0.16	0.04	1.5	1.97
MT	421,204	0.0005	0.03	0.02	0	0.18	0.23
LA	257,222	0.0003	0.02	0.01	0	0.11	0.14
OK	494,142	0.0005	0.04	0.02	0.01	0.21	0.28
OH	288,581	0.0003	0.02	0.01	0	0.13	0.16
MS	74,080	0.0001	0.01	0	0	0.03	0.04
SD	49,622	0.0001	0	0	0	0.02	0.02
NV	60,904	0.0001	0	0	0	0.03	0.03
AR	20,952	0	0	0	0	0.01	0.01

Production units (bbl).

Table 5-10. Federal Oil Emissions - Approved APDs Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	642,033,462	0.7122	51.04	30.42	6.51	278.44	366.42
NM	475,570,554	0.5277	37.8061	22.5295	4.8247	206.25	271.41
WY	68,149,392	0.0756	5.4176	3.2285	0.6914	29.56	38.9
ND	32,240,623	0.0358	2.563	1.5274	0.3271	13.98	18.4
CO	18,426,583	0.0204	1.4648	0.8729	0.1869	7.99	10.51
AK	17,195,382	0.0191	1.367	0.8146	0.1745	7.46	9.82
CA	12,777,923	0.0142	1.0158	0.6053	0.1296	5.54	7.29
UT	10,209,062	0.0113	0.8116	0.4836	0.1036	4.43	5.83
MT	2,027,806	0.0022	0.1612	0.0961	0.0206	0.88	1.16
LA	1,893,441	0.0021	0.1505	0.0897	0.0192	0.82	1.08
OK	1,841,881	0.002	0.1464	0.0873	0.0187	0.8	1.05
OH	561,945	0.0006	0.0447	0.0266	0.0057	0.24	0.32
MS	428,592	0.0005	0.0341	0.0203	0.0043	0.19	0.25
SD	375,696	0.0004	0.0299	0.0178	0.0038	0.16	0.21
NV	207,771	0.0002	0.0165	0.0098	0.0021	0.09	0.12
AR	126,811	0.0001	0.0101	0.006	0.0013	0.05	0.07

EUR Production units (bbl).

Table 5-11. Federal Gas Emissions - Approved APDs Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	1,112,382,433	0.0992	7.11	2.29	15.27	61.7	86.37
NM	672,095,453	0.0582	4.1702	1.35	8.96	36.18	50.66
WY	265,691,133	0.023	1.6486	0.53	3.54	14.3	20.02
AK	33,818,089	0.0029	0.2098	0.07	0.45	1.82	2.55
CO	83,937,900	0.0073	0.5208	0.17	1.12	4.52	6.33
UT	18,978,236	0.0016	0.1178	0.04	0.25	1.02	1.43
CA	18,944,507	0.0016	0.1175	0.04	0.25	1.02	1.43
ND	15,964,057	0.0014	0.0991	0.03	0.21	0.86	1.2
LA	11,257,131	0.001	0.0698	0.02	0.15	0.61	0.85
OH	16,937,211	0.0015	0.1051	0.03	0.23	0.91	1.28
OK	6,491,910	0.0006	0.0403	0.01	0.09	0.35	0.49
AR	967,108	0.0001	0.006	0	0.01	0.05	0.07
MT	462,579	0	0.0029	0	0.01	0.02	0.03
MS	226,955	0	0.0014	0	0	0.01	0.01
NV	308,041	0	0.0019	0	0	0.02	0.02
SD	120,212	0	0.0007	0	0	0.01	0.01

Production units (Mcf).

Table 5-12. Federal Gas Emissions - Approved APDs Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	3,844,539,748	0.3329	23.85	7.72	51.25	206.95	289.77
NM	1,928,856,607	0.167	11.9682	3.8711	25.7112	103.83	145.38
WY	1,254,067,898	0.1086	7.7813	2.5168	16.7164	67.51	94.52
AK	161,228,724	0.014	1.0004	0.3236	2.1491	8.68	12.15
CO	147,531,116	0.0128	0.9154	0.2961	1.9666	7.94	11.12
UT	106,275,160	0.0092	0.6594	0.2133	1.4166	5.72	8.01
CA	81,263,510	0.007	0.5042	0.1631	1.0832	4.37	6.12
ND	54,419,424	0.0047	0.3377	0.1092	0.7254	2.93	4.1
LA	36,766,523	0.0032	0.2281	0.0738	0.4901	1.98	2.77
OH	35,233,791	0.0031	0.2186	0.0707	0.4697	1.9	2.66
OK	27,332,437	0.0024	0.1696	0.0549	0.3643	1.47	2.06
AR	5,063,400	0.0004	0.0314	0.0102	0.0675	0.27	0.38
MT	2,600,092	0.0002	0.0161	0.0052	0.0347	0.14	0.2
MS	1,626,416	0.0001	0.0101	0.0033	0.0217	0.09	0.13
NV	1,321,358	0.0001	0.0082	0.0027	0.0176	0.07	0.1
SD	953,292	0.0001	0.0059	0.0019	0.0127	0.05	0.07

EUR Production units (Mcf).

Tables 5-13 through and 5-16 present the short-term projections of LCA emissions for reasonably foreseeable oil and gas production from potential new leases that will be sold during the next 12 months. The estimates shown assume all leases sold will be developed and begin a full 12 months of production during the next 12 months.

Table 5-13. Federal Oil Emissions - Potential Lease Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	128,104,041	0.1418	10.18	6.07	1.3	55.54	73.09
WY	69,658,043	0.0773	5.5376	3.3	0.7067	30.21	39.75
NM	29,395,175	0.0326	2.3368	1.3926	0.2982	12.75	16.78
AK	5,431,334	0.006	0.4318	0.2573	0.0551	2.36	3.1
UT	9,266,849	0.0103	0.7367	0.439	0.094	4.02	5.29
MT	3,790,833	0.0042	0.3014	0.1796	0.0385	1.64	2.16
CO	8,806,587	0.0098	0.7001	0.4172	0.0893	3.82	5.03
LA	668,776	0.0007	0.0532	0.0317	0.0068	0.29	0.38
MI	209,485	0.0002	0.0167	0.0099	0.0021	0.09	0.12
NV	304,518	0.0003	0.0242	0.0144	0.0031	0.13	0.17
TX	87,737	0.0001	0.007	0.0042	0.0009	0.04	0.05
MS	74,080	0.0001	0.0059	0.0035	0.0008	0.03	0.04
ND	105,062	0.0001	0.0084	0.005	0.0011	0.05	0.06
AL	56,273	0.0001	0.0045	0.0027	0.0006	0.02	0.03
ID	42,120	0	0.0033	0.002	0.0004	0.02	0.03
IL	29,926	0	0.0024	0.0014	0.0003	0.01	0.01
SD	24,811	0	0.002	0.0012	0.0003	0.01	0.01
OK	32,943	0	0.0026	0.0016	0.0003	0.01	0.01
OH	36,073	0	0.0029	0.0017	0.0004	0.02	0.03
AR	10,476	0	0.0008	0.0005	0.0001	0	0
NE	11,063	0	0.0009	0.0005	0.0001	0	0
CA	15,226	0	0.0012	0.0007	0.0002	0.01	0.01
KS	10,669	0	0.0008	0.0005	0.0001	0	0
WV	26,829	0	0.0021	0.0013	0.0003	0.01	0.01
PA	4,330	0	0.0003	0.0002	0	0	0
KY	4,330	0	0.0003	0.0002	0	0	0
NY	493	0	0	0	0	0	0

Production units (bbl).

Table 5-14. Federal Oil Emissions - Potential Lease Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	337,360,937	0.3744	26.82	15.98	3.42	146.33	192.57
WY	167,132,228	0.1854	13.2864	7.9177	1.6956	72.48	95.38
NM	57,502,292	0.0638	4.5712	2.7241	0.5834	24.94	32.82
AK	42,033,157	0.0466	3.3415	1.9913	0.4264	18.23	23.99
UT	27,381,530	0.0304	2.1767	1.2972	0.2778	11.88	15.63
MT	18,250,254	0.0202	1.4508	0.8646	0.1852	7.92	10.42
CO	15,091,455	0.0167	1.1997	0.7149	0.1531	6.55	8.62
LA	4,922,947	0.0055	0.3914	0.2332	0.0499	2.14	2.81
MI	1,321,900	0.0015	0.1051	0.0626	0.0134	0.57	0.75
NV	1,038,856	0.0012	0.0826	0.0492	0.0105	0.45	0.59
TX	468,073	0.0005	0.0372	0.0222	0.0047	0.2	0.26
MS	428,592	0.0005	0.0341	0.0203	0.0043	0.19	0.25
ND	370,582	0.0004	0.0295	0.0176	0.0038	0.16	0.21
AL	350,420	0.0004	0.0279	0.0166	0.0036	0.15	0.2
ID	202,781	0.0002	0.0161	0.0096	0.0021	0.09	0.12
IL	188,843	0.0002	0.015	0.0089	0.0019	0.08	0.11
SD	187,848	0.0002	0.0149	0.0089	0.0019	0.08	0.11
OK	122,792	0.0001	0.0098	0.0058	0.0012	0.05	0.07
OH	70,243	0.0001	0.0056	0.0033	0.0007	0.03	0.04
AR	63,406	0.0001	0.005	0.003	0.0006	0.03	0.04
NE	61,363	0.0001	0.0049	0.0029	0.0006	0.03	0.04
CA	51,943	0.0001	0.0041	0.0025	0.0005	0.02	0.03
KS	47,060	0.0001	0.0037	0.0022	0.0005	0.02	0.03
WV	45,490	0.0001	0.0036	0.0022	0.0005	0.02	0.03
PA	12,339	0	0.001	0.0006	0.0001	0.01	0.01
KY	12,339	0	0.001	0.0006	0.0001	0.01	0.01
NY	2,204	0	0.0002	0.0001	0	0	0

EUR Production units (bbl).

Table 5-15. Federal Gas Emissions - Potential Lease Projected 12-Months (Mt)

Area	Projected Production (12 months)	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	978,385,575	0.0845	6.07	1.96	13.04	52.65	73.72
WY	651,591,303	0.0564	4.043	1.3077	8.6855	35.08	49.12
AK	82,666,439	0.0072	0.5129	0.1659	1.1019	4.45	6.23
UT	50,901,165	0.0044	0.3158	0.1022	0.6785	2.74	3.84
NM	81,264,553	0.007	0.5042	0.1631	1.0832	4.37	6.12
CO	68,745,520	0.006	0.4266	0.138	0.9164	3.7	5.18
LA	29,268,540	0.0025	0.1816	0.0587	0.3901	1.58	2.21
MT	4,163,210	0.0004	0.0258	0.0084	0.0555	0.22	0.31
MI	662,212	0.0001	0.0041	0.0013	0.0088	0.04	0.05
NV	1,540,204	0.0001	0.0096	0.0031	0.0205	0.08	0.11
PA	1,503,747	0.0001	0.0093	0.003	0.02	0.08	0.11
WV	1,535,309	0.0001	0.0095	0.0031	0.0205	0.08	0.11
OH	2,117,151	0.0002	0.0131	0.0042	0.0282	0.11	0.16
AR	483,554	0	0.003	0.001	0.0064	0.03	0.04
TX	482,415	0	0.003	0.001	0.0064	0.03	0.04
OK	432,794	0	0.0027	0.0009	0.0058	0.02	0.03
MS	226,955	0	0.0014	0.0005	0.003	0.01	0.01
IL	94,602	0	0.0006	0.0002	0.0013	0.01	0.01
ND	183,495	0	0.0011	0.0004	0.0024	0.01	0.01
SD	60,106	0	0.0004	0.0001	0.0008	0	0
VA	79,079	0	0.0005	0.0002	0.0011	0	0
KY	79,079	0	0.0005	0.0002	0.0011	0	0
AL	79,079	0	0.0005	0.0002	0.0011	0	0
KS	98,440	0	0.0006	0.0002	0.0013	0.01	0.01
CA	77,010	0	0.0005	0.0002	0.001	0	0
ID	46,258	0	0.0003	0.0001	0.0006	0	0
NY	1,781	0	0	0	0	0	0
NE	1,575	0	0	0	0	0	0

Production units (Mcf).

Table 5-16. Federal Gas Emissions - Potential Lease Projected Life-of-Project (Mt)

Area	EUR Production	LCA CH4	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Federal Total	4,272,865,406	0.3699	26.51	8.58	56.96	230.02	322.05
WY	3,075,525,052	0.2663	19.0831	6.1724	40.996	165.56	231.81
AK	394,114,659	0.0341	2.4454	0.791	5.2534	21.22	29.71
UT	285,038,580	0.0247	1.7686	0.5721	3.7995	15.34	21.48
NM	233,222,335	0.0202	1.4471	0.4681	3.1088	12.55	17.57
CO	120,828,652	0.0105	0.7497	0.2425	1.6106	6.5	9.1
LA	95,592,959	0.0083	0.5931	0.1918	1.2742	5.15	7.21
MT	23,400,825	0.002	0.1452	0.047	0.3119	1.26	1.76
MI	10,390,884	0.0009	0.0645	0.0209	0.1385	0.56	0.78
NV	6,606,789	0.0006	0.041	0.0133	0.0881	0.36	0.5
PA	5,542,274	0.0005	0.0344	0.0111	0.0739	0.3	0.42
WV	5,213,301	0.0005	0.0323	0.0105	0.0695	0.28	0.39
OH	4,404,224	0.0004	0.0273	0.0088	0.0587	0.24	0.33
AR	2,531,700	0.0002	0.0157	0.0051	0.0337	0.14	0.19
TX	2,139,980	0.0002	0.0133	0.0043	0.0285	0.12	0.17
OK	1,822,162	0.0002	0.0113	0.0037	0.0243	0.1	0.14
MS	1,626,416	0.0001	0.0101	0.0033	0.0217	0.09	0.13
IL	1,484,412	0.0001	0.0092	0.003	0.0198	0.08	0.11
ND	625,511	0.0001	0.0039	0.0013	0.0083	0.03	0.04
SD	476,646	0	0.003	0.001	0.0064	0.03	0.04
VA	415,553	0	0.0026	0.0008	0.0055	0.02	0.03
KY	415,553	0	0.0026	0.0008	0.0055	0.02	0.03
AL	415,553	0	0.0026	0.0008	0.0055	0.02	0.03
KS	393,358	0	0.0024	0.0008	0.0052	0.02	0.03
CA	330,339	0	0.002	0.0007	0.0044	0.02	0.03
ID	260,009	0	0.0016	0.0005	0.0035	0.01	0.02
NY	38,944	0	0.0002	0.0001	0.0005	0	0
NE	8,736	0	0.0001	0	0.0001	0	0

EUR Production units (Mcf).

Figure 5-1 shows an annualized timeline of the projected short-term life-of-project emissions from the tables above for the selected state. The cumulative sum of all the state series is displayed in Table 5-17.

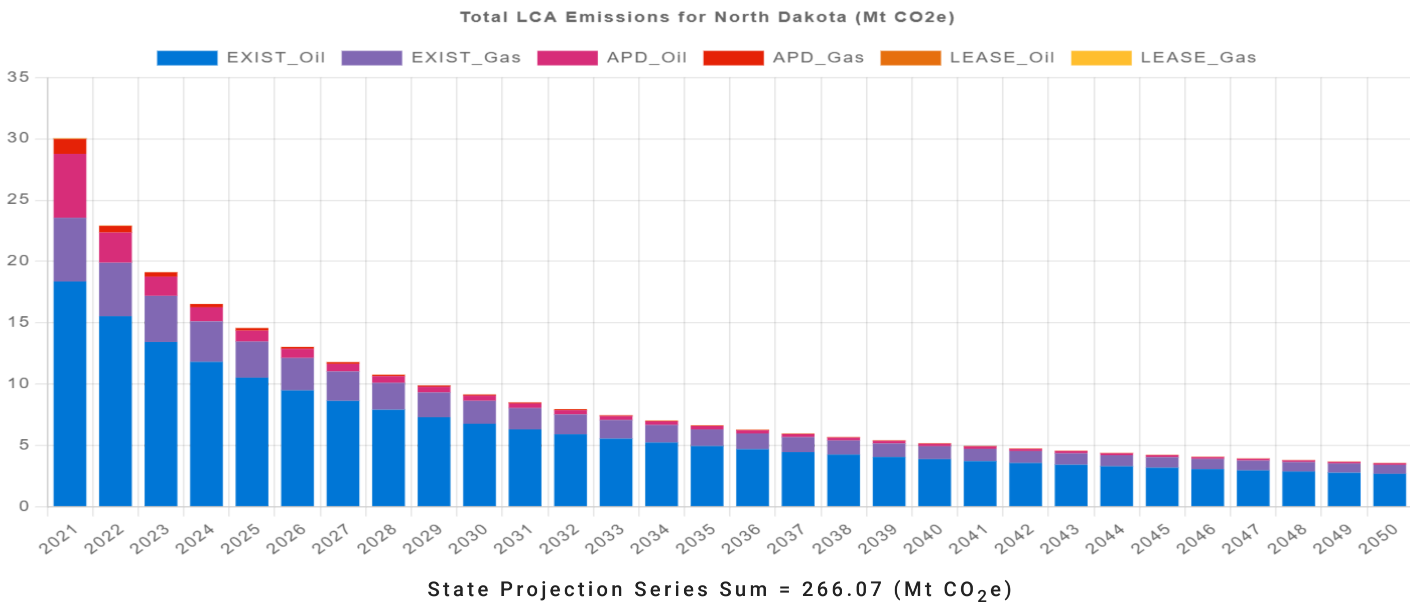


Figure 5-1. State Oil and Gas Emissions Timelines (North Dakota)

Table 5-17. Federal Summary - Projected Short-Term Life-of-Project Emissions (Mt)

Mineral	Extraction CO2e	Processing CO2e	Transport CO2e	Combustion CO2e	Total CO2e
Coal	5.6593	0	30.4683	509.92	546.06
Oil	225.8	134.56	28.81	1,231.86	1,621.07
Gas	221.15	71.54	475.11	1,918.66	2,686.44

5.3 Long-Term Federal Fossil Fuel Mineral Emissions Projections

The long-term emissions estimates presented in Figure 5-2 and Table 5-18 are based on 2021 EIA Annual Energy Outlook (AEO) data. Here the BLM is providing access to all of the AEO cases, as these explore a variety of market conditions including varying production, price, and overall economic growth rates. The difference (or delta) between the cumulative short-term emissions previously described and the long-term emissions estimates can be thought of as the level of additional development that could be authorized to sustain the existing federal fraction of production over the longer term. Similarly, if the short-term emissions exceed a longer term scenario, then the delta can be thought of as the amount of reduction required to attain the outlook forecast. In all cases, the EIA clearly explains that the AEO scenario projections are not predictions of what will happen, but rather, they are modeled projections of what may happen given certain assumptions.

For the 2021 AEO, the High Oil Price scenario produces the highest emissions. This should also be true at subnational scales depending on the production resource mix. However, areas with higher levels of coal production could see higher emissions even in a Low Oil and Gas supply scenario. For all areas (cumulative), the Low Oil Price case provides the lowest emissions, which is slightly counter intuitive considering that the Low Renewables Cost case would be expected to produce fewer emissions overall.

Table 5-18. Long-Range Federal Mineral Projections - AEO Reference Case

Federal Minerals	Federal Production	Energy (Quads)	Emissions (Mt CO_2e)
Coal (MM short tons)	5,325.36	132.7612	10,151.36
Oil (MM b/d)	24.43	51.6835	5,089.09
Gas (Tcf)	117.71	119.2700	8,871.90
Projected Totals	**NA**	**303.71**	**24,112.35**

> Onshore federal mineral estate
> AEO Total Projected U.S. Production - Reference Case: Coal = 14,449.67 (MM short tons), Oil = 397.24 (MM b/d), Gas = 1,161.80 (Tcf).

The projections made from the 2021 AEO data show that fossil fuel mineral development on federal land accounts for approximately 13.83% of total U.S. GHG emissions. The difference in federal emissions on an absolute basis between the High and Low AEO projection scenarios is approximately 2,164.4 Mt of CO_2e over the entirety of the projection period, or about 72.15 Mt of CO_2e on an annual average basis.

* * *

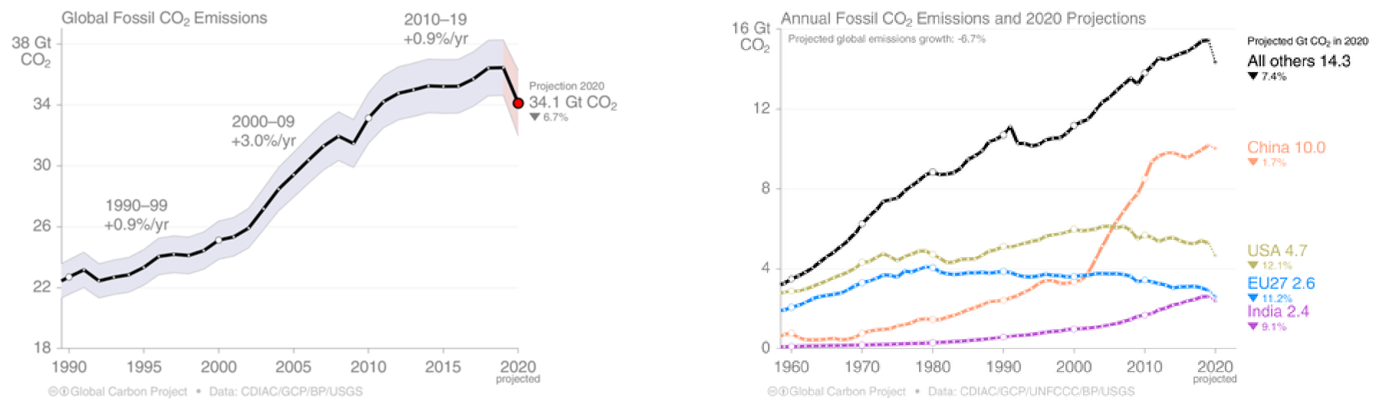
6.0 Global, National, and State GHG Emissions

This chapter provides background on cumulative GHG emissions at global, national, and state scales. Emissions are summarized from the latest global and national inventories for all sources and provide explicit accounting for GHGs from fossil fuel combustion. The chapter also documents projected emissions of GHGs at global and national scales. State-level data is provided for select categories of emitters (large sources and energy related sectors) from the various available databases subsequently described. This information is useful for providing the cumulative context for which the GHG emissions from BLM's fossil fuel authorizations are a part.

6.1 Annual Global Emissions

According to current data from the United Nations Emissions Gap Report (2020), and the Emissions Database for Global Atmospheric Research (EDGAR), total global GHG emissions grew in 2019 for the third year in a row and were estimated at 59,100 Mt (59.1 gigatonnes). This represents a 68% increase in global emissions relative to 1990 levels, a 50% increase over 2010 levels, and a 2.6% increase over the previous year's emissions due primarily to a significant increase in wildfires. In addition to increases in total GHG emissions, increases in CO_2 emissions attributable to fossil fuel use in industrial processes and combustion (fossil CO_2) were also reported. Global fossil CO_2 emissions were estimated at 38,000 Mt for 2019. This represents an increase in fossil CO_2 emissions of 1.0% over the previous year. To put the magnitude of 2019 global total GHG emissions and fossil CO_2 emissions into perspective, there is general consensus among climate scientists that to limit global temperature rise to 1.5°C and avoid serious climate changes, global emissions must drop to 25,000 Mt by 2030[20].

Figure 6-1a shows the global fossil CO_2 emissions between 1990 and 2019 and includes predicted emissions for 2020. Figure 6-1b shows the fossil CO_2 emissions for the largest emitting countries compared to the remaining countries. In 2019, the world's 6 largest emitters of fossil CO_2; China, the United States, India, the EU27+UK, Russia and Japan, together accounted for 51% of the population and emitted 67.0% of total global fossil CO_2 emissions. The largest emitter was China with 11,535 Mt or 30.3% of global CO_2 emissions followed by the U.S. with 5,107 Mt or 13.4% of the global emissions. The largest increases in emissions over the previous year were from China (3.4%) and India (1.6%). Decreases in fossil CO_2 emissions were achieved in the EU27+UK (-3.8%), the United States (-2.6%), Japan (-2.1%), and Russia (-0.8%)[21]. Early estimates of the impact of the COVID-19 pandemic and resulting economic crisis indicate that global energy related emissions fell by almost 6% in 2020 as demand for fossil fuels decreased by 4%-9%[22]. However, this decrease in demand and associated GHG emissions is expected to be short-lived as fossil fuel consumption is on the rise in 2021.



(a) (b)

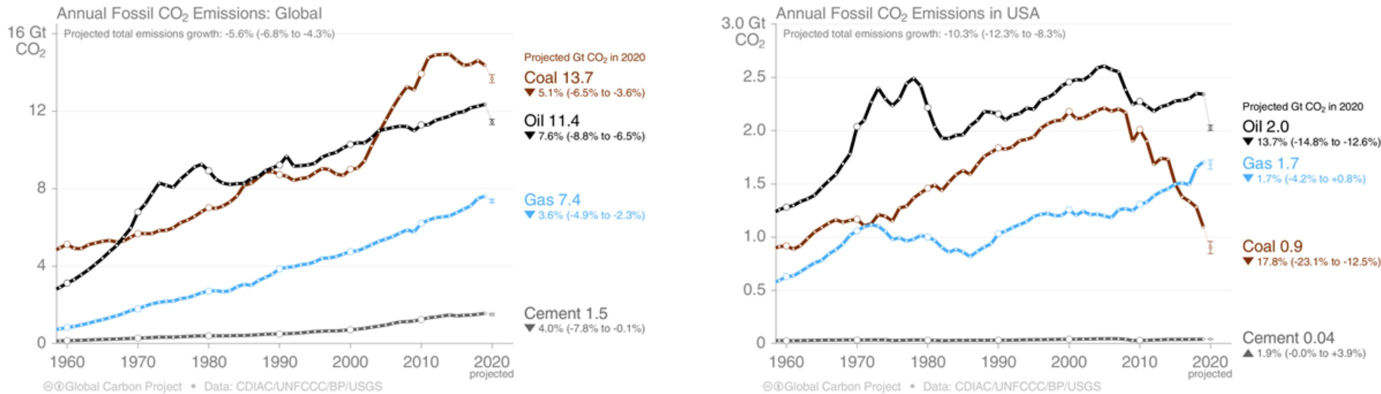
Figure 6-1. Global Fossil CO_2 Emissions

Globally, the use of all fossil fuels (coal, oil, gas, and peat), and the CO_2 emissions associated with the combustion of these fuels, continues to rise. Table 6-1 shows global total GHG emissions and U.S. fossil CO_2 emissions over the last decade. The U.S. fossil CO_2 emissions as a percent of global total GHG emissions has averaged nearly 10% during this time. Figure 6-2 shows global and U.S. CO_2 emissions from fossil fuel consumption between 1960 and 2020 for the three major fossil fuels and cement manufacturing (which releases CO_2 through chemical processes). The large increases in global coal emissions since 2000 can mostly be attributed to China's increase in coal fired power plants, while in the U.S. emissions from this fuel type continue to decline due in part to the competitiveness of natural gas and renewable sources of energy. CO_2 emissions from global oil combustion have remained steady over the last decade while emissions from oil in the U.S. increased in recent years due primarily to the increase from new production in basins such as the Permian and Williston and offshore regions. CO_2 emissions from natural gas have increased dramatically both globally and, in the U.S., due to increases in production and demand as a replacement fuel for coal. Table 6-2 shows global and U.S. fossil CO_2 emissions from the combustion of three fuel types (coal, oil, and gas) and the U.S. share of these emissions between 2010 and the year of most recent available data (2018).

Table 6-1. Total Global GHG Emissions 2010 – 2019 (Mt/yr)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Global - Total GHGs	50,100	53,000	54,000	54,700	52,700	52,700	52,800	53,500	55,300	59,100
U.S. - Fossil CO_2	5,568	5,439	5,264	5,337	5,413	5,249	5,153	5,083	5,244	5,107
U.S. Share	11.1%	10.3%	9.7%	9.8%	10.3%	10.0%	9.8%	9.5%	9.5%	8.6%

Source: https://edgar.jrc.ec.europa.eu/report_2020 and https://www.unep.org/emissions-gap-report-2020.



(a) (b)

Figure 6-2. Annual Fossil Fuel CO_2 Emissions (Global and U.S.)

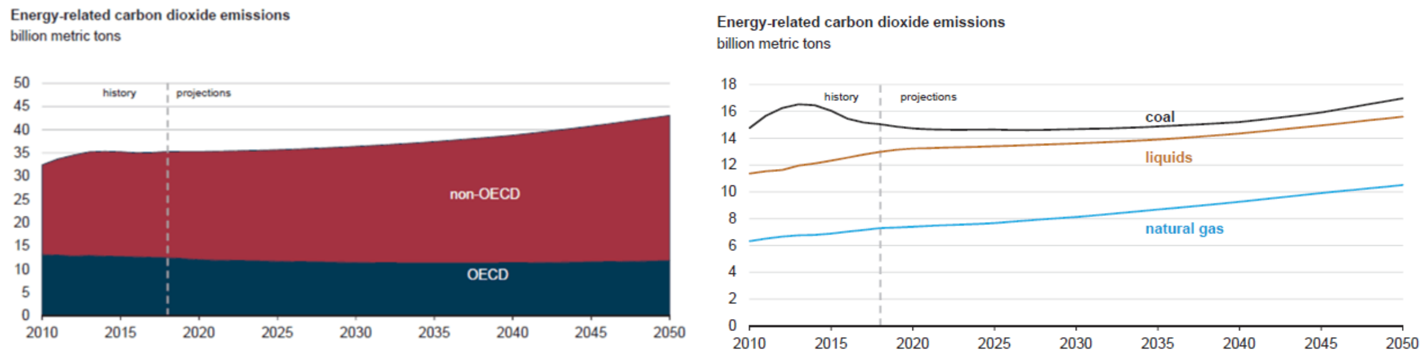
Table 6-2. Total CO_2 Emissions from Fossil Fuel Combustion (Mt/yr)

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Global - All fuels	30,582	31,459	31,806	32,371	32,389	32,366	32,375	32,837	33,513
U.S. - All fuels	5,352	5,128	4,903	5,039	5,047	4,929	4,838	4,761	4,921
U.S. All Fuels Share	17.5%	16.3%	15.4%	15.6%	15.6%	15.2%	14.9%	14.5%	14.7%
Global - Coal	13,828	14,584	14,714	15,020	14,989	14,607	14,343	14,506	14,766
U.S. - Coal	1,982	1,870	1,648	1,705	1,699	1,465	1,356	1,324	1,270
U.S. Coal Share	14.3%	12.8%	11.2%	11.4%	11.3%	10.0%	9.5%	9.1%	8.6%
Global - Oil	10,554	10,573	10,669	10,838	10,889	11,141	11,228	11,354	11,415
U.S. - Oil	2,060	1,929	1,870	1,926	1,914	1,984	1,992	1,981	2,031
U.S Oil Share	19.5%	18.2%	17.5%	17.8%	17.6%	17.8%	17.7%	17.4%	17.8%
Global - Gas	6,038	6,123	6,239	6,325	6,322	6,427	6,592	6,759	7,104
U.S. - Gas	1,287	1,304	1,361	1,386	1,412	1,459	1,470	1,437	1,601
U.S. Gas Share	21.3%	21.3%	21.8%	21.9%	22.3%	22.7%	22.3%	21.3%	22.5%

> Source: IEA https://www.iea.org/data-and-statistics/data-product/co2-emissions-from-fuel-combustion-highlights
> All Fuels – includes marine and aviation bunker fuels in addition to coal, oil, and gas.

6.2 Projected Global Emissions

The EIA provides long-term (2018–2050) world energy and emissions projections in its International Energy Outlook (IEO). The most recent IEO that contains CO_2 emissions data is the IEO2020, released in October 2020. The IEO provides several different scenarios to forecast future energy needs and associated carbon emissions. The Reference case reflects current trends and relationships among supply, demand, and prices in the future and is a reasonable baseline case to compare with cases that include alternative assumptions about the future energy system. Similar to the AEO report, IEO provides a Reference case that assumes energy consumption will rise nearly 50% between 2018 and 2050. Worldwide coal production and consumption is assumed to be steady at about 8 billion short tons, while demand for liquid fuels (oil) increases by 20%, and natural gas consumption increases more that 40% by 2050. Global energy related CO_2 emissions are projected to increase by 0.6% per year from 2018 to 2050 from about 35 billion metric tons CO_2 to about 43 billion metric tons. Although aggregate CO_2 emissions from the energy sector are projected to continue to rise, the carbon intensity of future energy sources (i.e., the amount of CO_2 emissions produced per unit of energy used) is projected to decrease indicating that sources of energy that do not produce CO_2 emissions (e.g., renewables) will comprise a larger portion of meeting future energy demands. Figure 6-3 (EIA graphs) shows both the last decade of estimated CO_2 emissions from global fossil fuel combustion and the projected emissions out to 2050. The data is displayed separately for countries that are a part of the Organization of Economic Cooperation and Development (OECD), of which the U.S. is a part, and those that are not.



(a) (b)

Figure 6-3. Reference Case – Future Global Energy Related CO_2 Emissions

6.3 Annual U.S. Emissions

The U.S. EIA provides information on energy related CO_2 emissions in its Monthly Energy Review (MER). The January 2021 edition of the MER shows that U.S. energy-related CO_2 emissions fell by an estimated 11% from 5,140 Mt in 2019 to 4,571 Mt in 2020, largely because of reduced travel and other factors that led to less energy consumption during the COVID-19 pandemic. Emissions from coal combustion in the U.S. comprised 19% of the energy consumption emissions while oil and gas consumption accounted for 45% and 36% of emissions, respectively.

The U.S. EPA provides a comprehensive accounting of total GHG emissions for all man-made sources in the United States. The results of these tracking and quantification efforts are published in the annual Inventory of U.S. Greenhouse Gas Emissions and Sinks. The inventory report is a top-down assessment of national annual GHG emissions and is prepared to comply with commitments under the United Nations Framework Convention on Climate Change (UNFCCC). The EPA generally uses national energy data, data on national agricultural activities, and other national statistics to provide a comprehensive accounting of total GHG emissions. The use of the aggregated national data results in total coverage of sources including small emitters but means that the national emissions estimates for most source categories are not broken down at the geographic or facility level.

According to the latest version of the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019 (EPA, 2021) released in April 2021, total U.S. GHG emissions were 6,558.3 Mt of CO_2e in 2019, a decrease of approximately 1.7% from the previous year and a decrease of 13% from the peak emissions in 2005. The decrease in total GHG emissions between 2018 and 2019 was largely driven by the decrease in CO_2 emissions from fossil fuel combustion primarily from shifts in the electrical power sector from coal to gas and other renewables. However, 82% (5,392 Mt) of the total emissions were due to energy production and use, primarily fossil fuel combustion for transportation and electricity generation. The tonnages presented in this paragraph were calculated by EPA using GWPs from the IPCC's AR4. The EPA also presents emissions estimates using GWPs from IPCC's AR5 in the Annexes to the Inventory of U.S. GHG Emissions and Sinks.

The primary GHG emitted by human activities in the U.S. was CO_2, representing approximately 80% of total 2019 GHG emissions. The largest source of CO_2, and of overall GHG emissions, was fossil fuel combustion (4,857 Mt). CH_4 emissions from all sectors (673.51 Mt) accounted for 10% of emissions and increased slightly for the first time since 2011. The major sources of CH_4 include natural gas systems, enteric fermentation and manure management associated with domestic livestock, and decomposition of wastes in landfills. N_2O emissions accounted for 7% of total GHG emissions. The agricultural sector including fertilizers and soil management and manure management was the largest source of N_2O emissions. Figure 6-4a shows total U.S. GHG emissions by greenhouse gas.

The EPA GHG inventory report includes emissions data broken out by five different emissions sectors. The Energy sector includes three different subcategories; coal mining, natural gas and petroleum systems, and fossil fuel combustion. The emissions itemized under the coal mining and natural gas and petroleum systems subcategories include emissions for all U.S. sources in each of these categories and are not differentiated by mineral ownership (i.e., federal, state, or private minerals). The coal mining sector includes emissions from underground and surface mining as well as post mining activities and abandoned underground mines. In 2019, GHG emissions from this subcategory were 53.31 Mt a decrease of 9.5% from the previous year. Figure 6-4b shows a dramatic decrease in coal mining emissions since 2010 and an overall decrease in emissions of 49% since 1990 from this subcategory.

The natural gas and petroleum systems subcategory includes emissions from oil and gas exploration, production, and processing as well as other sources. In 2019, GHG emissions from this subcategory were 287.83 Mt, an increase of 7.3% from the previous year. Figure 6-4c shows a steady increase in emissions from this subcategory since the low point in 2016, but overall emissions have remained fairly steady since 1990 with an overall increase of 1.2% from this subcategory.

The fossil fuel combustion subcategory includes emissions from use of fossil fuels in transportation, electricity generation, industry, and residential use. In 2019, emissions from this subcategory were 4,856.7 Mt, down 2.7% from the previous year and down 15.6% from the peak in 2007. Figure 6-4d shows the CO_2 emissions from fossil fuel combustion since 1990.

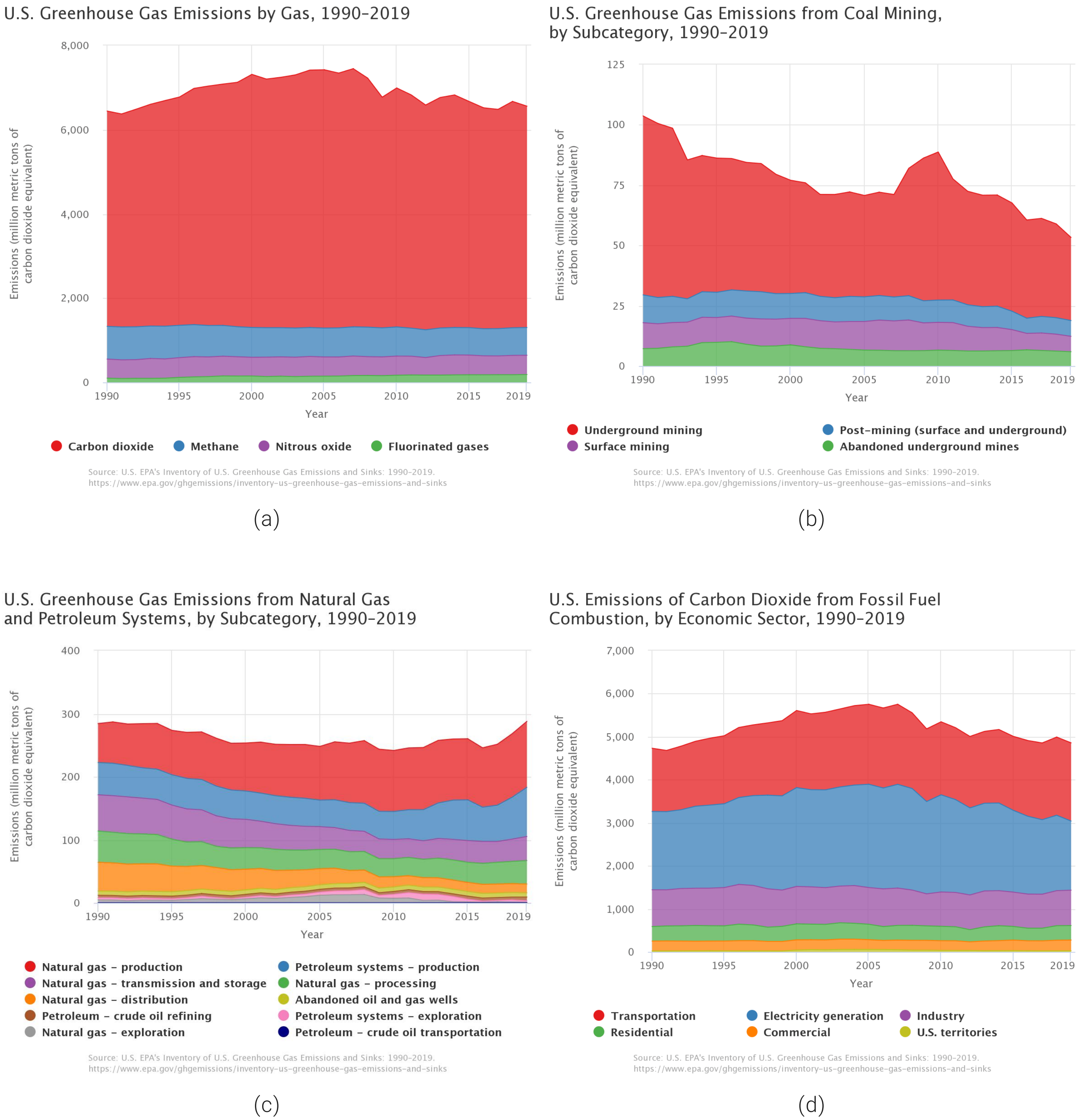


Figure 6-4. U.S. GHG Emissions

6.4 Projected U.S. Emissions

In addition to providing long-term projections for global energy demand and associated CO_2 emissions, the EIA produces an assessment of domestic energy and emissions trends through 2050 in its AEO report (as discussed in chapter 4). The AEO projections for energy-related CO_2 emissions from fossil fuel consumption generally show a slight decrease in emissions over the next decade due primarily to significant decreases in coal consumption and a rise in the use of natural gas and renewable energy sources to meet demand. However, U.S. CO_2 emissions from energy consumption are expected to increase beyond 2035 due to increases in population and economic growth and the associated increases in oil and natural gas consumption. Figure 6-5 shows the projected changes in U.S. fossil fuel use through 2050.

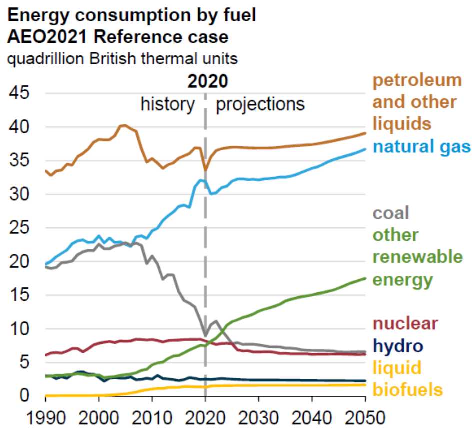


Figure 6-5. U.S. Projected Energy Mix (2021 AEO)

6.5 State Emissions

Each year, the U.S. EPA and the EIA compile data on GHG emissions at the state level as well as nationally. The EPA collects detailed emissions data from the largest greenhouse gas emitting facilities in the U.S. through its GHG Reporting Program (GHGRP). Large emitters of GHG emissions (> 25,000 tons/year) in each state are required to report their annual emissions along with other relevant facility data. Approximately 8,000 facilities report their emissions annually. The data is compiled by facility and by state and are available through EPA's Facility Level Information on GreenHouse gases Tool (FLIGHT). The GHGRP data are useful for understanding the major sources and types of GHG emissions within a state; however, it is not a comprehensive emissions inventory for each state as many sources of emissions (e.g., agriculture and land use sectors) are not required to report. The EPA has estimated that GHGRP reporting covers approximately 85% of the total GHG emissions for sector-specific sources. The EIA issues its State Energy-Related Carbon Dioxide Emissions Tables on an annual basis that show CO_2 emissions from fossil fuel use for sources across all sectors of the economy (residential, commercial, industrial, transportation, and electricity generation). Table 6-3 shows GHG emissions as reported to EPA for the states in which the BLM authorizes leasing and development of federal fossil fuel minerals. Information is shown for total reported GHG emissions from all facilities in each state as well as for two subcategories; power plants that consume coal or natural gas, and petroleum and natural gas systems that produce or consume oil or gas. The table also shows CO_2 emissions from the combustion of fossil fuels in each state as estimated by EIA.

Table 6-3. State GHG Emissions (Mt/yr CO_2)

State	EPA GHGRP Total Reported	EPA GHGRP Power Plants	EPA GHGRP Petroleum & Natural Gas Systems	EIA Energy Related Emissions
Alabama	80.9	51.6	2.3	113.4
Alaska	14.4	3.1	8.5	35.2
Arkansas	41.8	33	0.4	71.4
California	93.2	31.2	5.7	362.5
Colorado	45.3	34.3	4.3	89.3
Idaho	5.1	1.7	0.3	19
Illinois	96.4	59.4	1.8	210.2
Kansas	34.1	20.5	2.2	62.4
Kentucky	78.4	58.7	1.1	120.7
Louisiana	146.3	40.1	22.8	210.8
Michigan	79.5	56.5	2.2	162.1
Mississippi	39.8	25.2	1.9	69.4
Montana	20.9	16.4	0.9	30.7
Nebraska	28.9	21	0.4	52.7
Nevada	17.1	13.8	0.3	37.9
New Mexico	29.7	21.4	5	45.4
New York	34.5	23.6	2	167.5
North Dakota	37.8	28.2	2.4	59.2
Ohio	104.6	67.2	3.3	208.6
Oklahoma	51.4	28.4	4.5	97.9
Pennsylvania	114.5	77.3	3.5	221.3
South Dakota	6.4	3.3	0	15.6
Texas	380.5	203.4	30.9	701.1
Utah	36	28	0.9	60.3
Virginia	42.6	27.5	0.6	103.1
West Virginia	74.7	56.5	2	89.9
Wyoming	54.5	39.1	5.2	63.6

> EPA FLIGHT data (large emitters), and EIA State Energy related CO_2 emissions data.
> EPA and EIA state emissions data does not include emissions from agriculture or waste management.

* * *

7.0 Emissions Analysis

For the purposes of NEPA analyses, the BLM uses the decision scope emissions (i.e., reasonably foreseeable GHG emissions) of a proposed federal action as a proxy for assessing climate impacts. Published climate impact predictions associated with various global emissions scenarios are described in the NEPA analysis and are compared to the decision scope emissions levels to provide a basis for considering the magnitude, or range of impacts, that could follow from the proposed action. This methodology for assessing climate-related impacts is in line with previously issued guidance[23] and has obvious benefits in that emissions calculations are relatively straightforward and can be clearly explained if properly documented. More specifically, the proxy approach was adopted because of the lack of climate analysis tools and techniques that lend themselves to describing the physical climate or earth system responses, such as changes to sea level, average surface temperatures, or regional precipitation rates, that could be attributable to emissions associated with any single action or decision. Comparing proxy emissions at various scales relative to a quantity of emissions known to have a definitive climate impact (i.e., modelled emissions) allows the BLM to provide a clearly understandable sense of the intensity for an action relative to the magnitude of the issue. Further, there are no established emissions thresholds for NEPA analysis to contextualize the quantifiable GHG emissions of an action or decision in terms of environmental effects. Although future policy may prescribe an emissions threshold for analysis, the implications of such a limit (physical or otherwise) are beyond the scope of this report to contemplate presently. One of the drawbacks of the proxy emissions method is the difficulty in downscaling the published climate impacts (predicted or observed) relative to the federal action emissions, which are typically several orders of magnitude smaller than the emissions levels associated with the published impacts. Still, comparing emissions levels between proposed actions, current emissions and conditions, and published predictions based on forecasted emission scenarios allows decisionmakers to form a qualitative judgment about the potential for climate impacts from a proposed action.

7.1 Emissions Comparisons

The annual global and U.S. emissions data presented in chapter 6 can be compared with the estimated annual GHG emissions from BLM fossil fuel authorizations in chapter 5 to provide context around the scale and potential impact of estimated emissions from BLM's fossil fuel authorizations. Evaluating the magnitude of estimated emissions from a particular category in the context of other categories or total geographic emissions is one way to evaluate their relative potential impact on climate change. A comparative analysis is also useful for informing policy and planning decisions and to identify options for maximizing the effectiveness of mitigation and emissions reduction strategies. Table 7-1 compares the magnitude of BLM's estimated emissions to global and U.S. emissions at different scales. For example, the table shows that the emissions associated with the BLM's authorizing of leasing and extraction of federal minerals on public lands, (i.e., direct emissions from coal, oil, and gas) comprise 0.09% of global emissions and 0.8% of U.S. emissions. The total emissions from coal, oil, and gas development and end-use comprise 1.6% of global emissions and 14.0% of U.S. emissions. It is important to note that the U.S. emissions shown in the table (U.S. total, energy production, fossil fuel combustion, coal mining, and natural gas and petroleum systems) are derived using GWPs from IPCC AR4 to convert to CO_2 equivalents, whereas BLM emissions are derived using GWPs from IPCC AR5 (see Table 3-1). This may result in a slight overestimation of BLM's share of U.S. emissions in the table.

Table 7-1. BLM Share of 2019 Annual Global and U.S. GHG Emissions

Emissions Category	Annual Emissions (Mt)	BLM Share				
		Total Emissions All fuels	Indirect Emissions All Fuels	Direct Emissions All Fuels	Direct Emissions Oil and Gas	Direct Emissions Coal Mining
Global - Total GHG Emissions	59,100.00	1.6%	1.5%	0.09%	0.1%	0.0%
Global - Fossil Fuel Combustion	33,513.25	2.7%	2.6%	0.15%	0.1%	0.0%
U.S. Total GHG Emissions	6,558.30	14%	13.2%	0.8%	0.7%	0.1%
U.S. Energy Production	5,392.27	17%	16.1%	0.9%	0.8%	0.1%
U.S. Fossil Fuel Combustion	4,856.70	18.9%	17.9%	1.0%	0.9%	0.1%
U.S. Coal Mining	53.31	NA	NA	NA	NA	9.1%
U.S. Natural Gas and Petroleum Systems	287.83	NA	NA	NA	15.8%	NA
BLM Total GHGs from all Fossil Fuel Authorizations	918.64	100%	94.5%	5.5%	4.9%	0.5%
BLM Indirect GHG Emissions from all Fossil Fuel Authorizations	868.36	NA	100%	NA	NA	NA
BLM Direct GHG Emissions from all Fossil Fuel Authorizations	50.28	NA	NA	100%	90.4%	9.6%
BLM Direct GHG Emissions from Oil and Gas Authorizations	45.43	NA	NA	NA	100%	NA
BLM Direct GHG Emissions from Coal Authorizations	4.85	NA	NA	NA	NA	100%

Not applicable "NA" cells are irrelevant to calculated data columns.

Table 7-2 presents emissions data for large emitters and energy-related CO_2 emissions for the states in which the BLM has authorized leasing and development of federal fossil fuel minerals. The annual emissions data from the EPA and EIA (see Chap. 6) are compared to the BLM's estimated annual direct emissions in each state for the report year. The BLM-authorized direct emissions are used for comparison rather than total emissions, because the direct emissions reflect the portion of emissions known to occur in that state. Emissions from processing, transport, and downstream combustion (indirect) may or may not occur in the state where the minerals were first extracted. Although the BLM has attributed indirect emissions to the state where the minerals are extracted for accounting purposes in Chapter 5 of this report, that approach is not valid for state-level comparison purposes in this chapter. For example, more than 80% of the coal extracted from federal minerals in Wyoming is transported and combusted outside of Wyoming. If the total BLM-authorized emissions (direct and indirect) in Wyoming were compared to EPA FLIGHT data and EIA state data for Wyoming, it would appear that BLM emissions in Wyoming comprised 912% of Wyoming's large emitters and 782% of Wyoming's energy-related CO_2 emissions. This is nonsensical, so a comparison of total emissions at the state scale is not valid. Total emissions are compared to global and national emissions in Table 7-1. Instead, Table 7-2 shows that the BLM's direct emissions in Wyoming are equivalent to 26% of emissions from large emitters in Wyoming and equivalent to 23% of energy-related emissions in Wyoming. This example illustrates that it is valid to compare BLM total emissions at U.S. and global scales and to compare BLM direct emissions at the state scale.

Table 7-2. BLM Share of State Annual GHG Emissions (MMT CO_2)

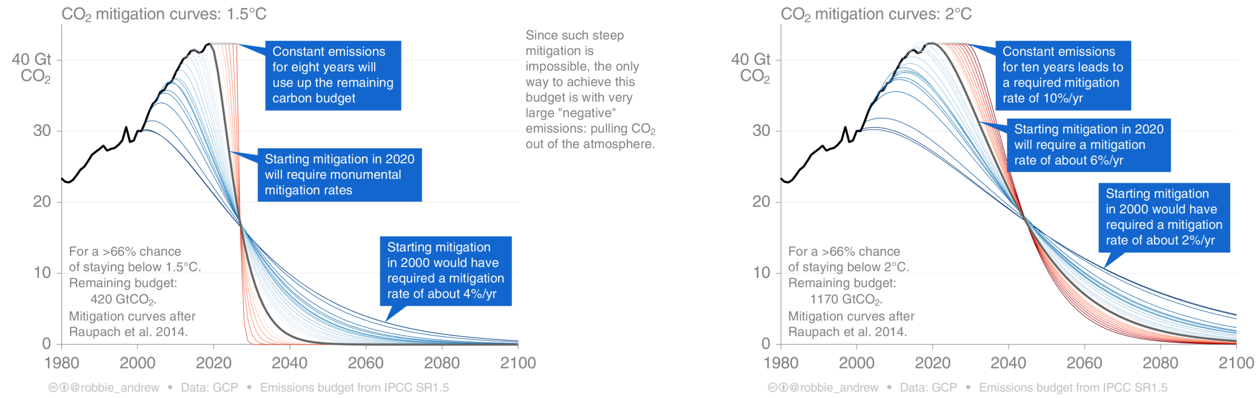
State	BLM Fossil Fuel Authorizations Direct Emissions	EPA GHGRP Large Emitters	BLM Share of Large Emitters	EIA Energy Related Emissions	BLM Share of Energy Related Emissions
Alabama	0.1	80.9	0.1%	113.4	0.1%
Alaska	0.19	14.4	1.3%	35.2	0.5%
Arkansas	0.05	41.8	0.1%	71.4	0.1%
California	0.8	93.2	0.9%	362.5	0.2%
Colorado	4.75	45.3	10.5%	89.3	5.3%
Idaho	<0.001	5.1	0%	19	0%
Illinois	<0.001	96.4	0%	210.2	0%
Kansas	0.03	34.1	0.1%	62.4	0.05%
Kentucky	<0.001	78.4	0%	120.7	0%
Louisiana	0.21	146.3	0.1%	210.8	0.1%
Michigan	0.01	79.5	0%	162.1	0.005%
Mississippi	0.02	39.8	0%	69.4	0.03%
Montana	0.49	20.9	2.4%	30.7	1.6%
Nebraska	<0.001	28.9	0%	52.7	0%
Nevada	0.02	17.1	0.1%	37.9	0.1%
New Mexico	23.37	29.7	78.7%	45.4	51.4%
New York	<0.001	34.5	0%	167.5	0%
North Dakota	3.69	37.8	9.8%	59.2	6.2%
Ohio	0.02	104.6	0%	208.6	0.01%
Oklahoma	0.16	51.4	0.3%	97.9	0.2%
Pennsylvania	<0.001	114.5	0%	221.3	0%
South Dakota	0.01	6.4	0.2%	15.6	0.1%
Texas	0.16	380.5	0%	701.1	0.02%
Utah	1.69	36	4.7%	60.3	2.8%
Virginia	<0.001	42.6	0%	103.1	0%
West Virginia	<0.001	74.7	0%	89.9	0%
Wyoming	14.5	54.5	26.6%	63.6	23%

7.2 Carbon Budgets and Carbon Neutrality

Carbon neutrality, or net zero emissions, is maintaining a balance between emitting and absorbing GHGs from the atmosphere. On a global scale, carbon neutrality would result in atmospheric concentrations of GHGs reaching an equilibrium, which could stabilize climate change and limit global warming. Under the 2015 Paris Agreement, countries agreed to cut GHG emissions with the goal of holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels in order to avoid some of the more dire consequences associated with climate change. Carbon budgets are an estimate of the amount of additional GHGs that could be emitted into the atmosphere over time to reach carbon neutrality while still limiting global temperatures to no more than 1.5°C or 2°C above pre-industrial levels. At the time of this draft, the IPCC Special Report on Global Warming of 1.5ºC (2018) is the most widely accepted authority on the development of a carbon budget to meet the goals of the Paris Agreement. Other organizations have also developed carbon budgets for specific sectors and emissions and temperature targets. For example, the International Energy Agency (IEA) developed its carbon budget focused on the energy sector in its report on achieving Net Zero by 2050. The International Renewable Energy Agency (IRENA) developed a carbon budget focused on rapid transition from fossil fuels for its Renewables Energy Outlook and its World Energy Transitions Outlook.

Carbon budgets are dependent on the key assumptions and parameters used to develop the budget such as source sectors for emissions, GHGs included, temperature targets, climate sensitivity, and estimates of cumulative carbon emissions that have already occurred. For example, scientists recently revised the IPCC budget to account for problems associated with the Earth System Models used in the AR5 budget estimates[24]. These models underestimated historical cumulative CO_2 emissions and were projecting temperatures warmer than have been observed. The new estimates rely on observational constraints to make the budget calculations, which have been widely accepted by climate scientists as being more accurate.

Carbon budget estimates are expressed as the remaining cumulative CO_2 emissions from a base year (most recently 2018) until the time when net zero global emissions can be achieved. The IPCC budget suggests a range of approximately 420 $GtCO_2$ for a 66% chance of limiting warming to 1.5°C to 840 GtCO2 for a 33% chance. Similarly, estimates for the 2°C probabilities range from 1,170 to 2,030 $GtCO_2$. These estimates contain uncertainties that are characteristic of scientists' current understanding of the Earth's climate influencing systems, such as feedbacks and the forcing and response associated with the non-CO_2 GHG species, and historical emissions accounting. The uncertainty range associated with the new estimates is approximately ±400 Gt CO_2. Because the IEA and IRENA derived carbon budgets fall within this range of uncertainty, the BLM primarily discusses the IPCC budgets in this report. Staying within the 1.5°C carbon budget implies that CO_2 emissions need to start declining this decade to maintain reasonable progress to reach net zero by about 2050, or 2100 for the 2°C budget. Figure 7-1 outlines what an emissions reduction curve under either scenario might look like. **Note:** The 1.5°C pathway to neutrality assumes a higher degree of emissions reduction than pledges made under the Paris Agreement.



(a) (b)

Figure 7-1. Carbon Budget Mitigation Pathways

Annually, the United Nations (UN) publishes an emissions gap report which provides an assessment of how actions and pledges of countries affect global GHG emissions trends and how these trends compare to emissions trajectories that are consistent with long-term goals for limiting global warming (UN 2020). Specifically, the emissions gap is the difference between GHG emissions levels consistent with limiting global warming to 1.5°C or 2.0°C and the emissions levels consistent with current reduction commitments by member nations. By 2030, the UN estimates that to limit warming to 2.0°C or 1.5°C, global annual emissions should be approximately 41 $GtCO_2e$ and 25 $GtCO_2e$, respectively. Based on current emissions pledges, the global emissions gap in 2030 would be 15 $GtCO_2e$ above the 2.0°C warming goal and 32 $GtCO_2e$ above the 1.5°C warming goal. To bridge the gap, nations must implement policies to strengthen emissions reductions commitments threefold to achieve the 2.0°C goal and fivefold to achieve the 1.5°C goal. Delaying the implementation of stronger policies would require even more stringent emissions reduction policies to achieve warming goals.

The IEA "Net Zero by 2050" report found that current global emissions commitments fall short of those needed to limit global warming to 1.5 ºC above pre-industrial levels. The IEA identifies a narrow pathway that reaches global net-zero emissions by 2050 and limits warming to 1.5 ºC, but it requires countries to strengthen and successfully implement energy and climate policies. This emissions pathway requires clean energy investment, innovation to bring new clean energy technologies to market, a shift away from technology that uses fossil fuels, a focus on transitioning people's behavior and jobs for a new energy sector, and international cooperation. Under this emissions pathway, fossil fuel use in the energy sector would fall from four-fifths of all supply to one-fifth by the year 2050. While the IEA identified a global pathway, each country needs to design its own strategy for achieving carbon neutrality.

Executive Order 14008, "Tackling the Climate Crisis at Home and Abroad" (January 27, 2021), directs the executive branch to establish policies or rules that put the United States on a path to achieve carbon neutrality, economy-wide, by no later than 2050. This goal is consistent with IPCC's recommendation to reduce net annual global CO_2 emissions between 2020 and 2030 in order to reach carbon neutrality by mid-century. Since the EO was issued earlier in 2021, federal agencies are still in the process of developing policies that align with a goal of carbon neutrality by 2050.

None of the global carbon budgets are a hard line that countries have committed to stay within as part of the Paris Agreement or otherwise. Carbon budgets were originally envisioned as being a convenient tool to simplify communication of a complex issue and to assist policymakers considering options for reducing GHG emissions on a national and global scale. Carbon budgets have not yet been established on a national or subnational scale, primarily due to the lack of consensus on how to allocate the global budget to each nation, and as such the global budgets that limit warming to 1.5 ºC or 2.0 ºC are not useful for BLM decisionmaking as it is unclear what portion of the budget applies to emissions occurring in the United States. However, stakeholders and members of the public have requested that the BLM consider comparing its predicted emissions in the context of global carbon budgets.

Table 7-3 provides an estimate of the potential emissions associated with BLMs fossil fuel authorizations in relation to IPCC carbon budgets. The BLM projected life-of-project emissions from existing and foreseeable federal fossil fuel (oil, gas, and coal) development (see Chapter 5) are used here for the carbon budget analysis. Oil and gas projected life-of-project emissions are scaled (i.e., time to exhaust budget ÷ 30-year life of project) to the timeframe in which global emissions will exhaust the budget in order to show the portion of the budget that is consumed by federal emissions. Since foreseeable federal coal emissions are only projected for 1 year, it is assumed that the projected 2021 annual federal coal emissions will continue for the entire timeframe in which budgets are exhausted. This is likely an overestimate since coal reserves on federal lease tracts will be depleted over time. The BLM estimated emissions include direct emissions as well as transport and downstream combustion emissions. It is important to note that this comparison of BLMs estimated emissions from fossil fuel authorizations to global carbon budgets does not portray the full picture of carbon flux (amount emitted vs. amount stored/sequestered/offset) on public lands. Results of the carbon budget analysis are presented as the percent of the budget consumed by federal fossil fuel emissions and the difference in time it takes to consume the budget with and without federal fossil fuel emissions. The results in the table reflect only the emissions side of the equation and may overestimate actual consumption of global carbon budgets resulting from BLM leases and authorizations. The U.S. Geological Survey estimated that sequestration on federal lands offset approximately 15% of CO_2 emissions resulting from the extraction and end-use combustion emissions of fossil fuels on federal lands. In future annual iterations of this report, the BLM may refine this carbon budget evaluation based on new or improved emissions and sequestration information on public lands, and on potential future U.S. policies establishing carbon neutral emissions pathways.

Table 7-3. Evaluation of Potential Federal Fossil Fuel GHG Emissions with Respect to Global Carbon Budgets

		1.5 Deg C			2.0 Deg C		
Minerals[1]	**Metric**	**33%**	**50%**	**66%**	**33%**	**50%**	**66%**
	Carbon Budget ($GtCO_2$)	840	580	420	2,030	1,500	1,170
	Time to Exhaust Budget (years)[2]	14.21	9.81	7.11	34.35	25.38	19.8
Federal Oil and Gas	Federal Emissions During Budget Timeframe ($GtCO_2$)	4.67	3.15	2.24	11.68	8.55	6.58
	Federal Consumption of Budget (%)	0.56%	0.54%	0.53%	0.58%	0.57%	0.56%
	Time to Exhaust Budget without Federal Emissions (years)	14.29	9.87	7.14	34.55	25.53	19.91
	Reduction in Time to Exhaust Budget from Federal Emissions (days)	-29	-20	-14	-73	-53	-41
Federal Coal	Federal Emissions During Budget Timeframe ($GtCO_2$)	7.39	5.30	3.91	16.5	12.39	9.97
	Federal Consumption of Budget (%)	0.88%	0.91%	0.93%	0.81%	0.83%	0.85%
	Time to Exhaust Budget without Federal Emissions (years)	14.34	9.90	7.17	34.63	25.59	19.97
	Reduction in Time to Exhaust Budget from Federal Emissions (days)	-46	-33	-24	-103	-77	-62
Federal Oil, Gas & Coal	Federal Emissions During Budget Timeframe ($GtCO_2$)	12.05	8.44	6.16	28.18	20.94	16.55
	Federal Consumption of Budget (%)	1.44%	1.46%	1.47%	1.39%	1.40%	1.41%
	Time to Exhaust Budget without Federal Emissions (years)	14.42	9.96	7.21	34.83	25.74	20.08
	Reduction in Time to Exhaust Budget from Federal Emissions (days)	-75	-53	-38	-175	-130	-103

[1] Based on Long-term Onshore Federal Mineral Emissions estimated from the EIA AEO reference case energy projection scenario. Does not include sequestration by federal lands or other federal emissions offsets.
[2] Based on the global emissions from the 2020 UN Emissions Gap Assessment, 59.1 Gt CO_2e.

7.3 Climate Impact Modeling

To move beyond the emissions as a proxy approach for ascribing climate impact attribution as a result of BLM-authorized emissions, the Bureau has been investigating the use of reduced complexity climate models to analyze such emissions for the purposes of obtaining actual earth system responses that could be attributable to the federal decision scope over which the BLM has purview. Most simple climate models are based in part on global average energy-balance equations, and a few incorporate additional processing modules to better account for some of the more complex feedback mechanics. The Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) stands out as a potential resource due to its ease of use (online access), flexibility, robustness, and overall transparency. As described on the model's wiki page, "MAGICC is designed to provide maximum flexibility in order to match different types of responses seen in more sophisticated models, the approach in MAGICC's model development has always been to derive the simple equations as much as possible from key physical and biological processes." This process-based approach has a strong conceptual advantage in comparison to simple statistical fits that are more likely to quickly degrade when emulating scenarios outside the original calibration space of the sophisticated models. From a user's perspective, the platform offers detailed documentation and baseline scenario emissions input files that are easily modified to suit the BLM's needs. Figure 7-2 shows MAGICC's conceptual model workflow.

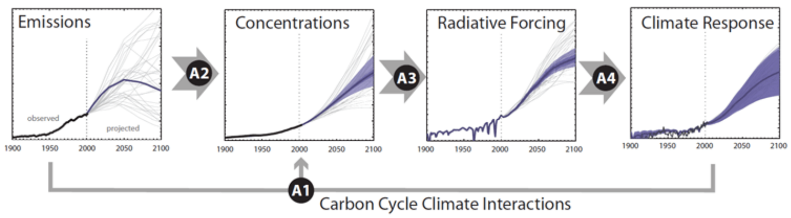


Figure 7-2. MAGICC Model Calculation Workflow[25]

The BLM has constructed a single run of MAGICC utilizing the 2.6 Representative Concentration Pathway emissions scenario (discussed further in Chapter 9). Run emissions were prepared by subtracting federal fossil fuel emissions of CO_2 (as GtC) from the baseline scenario emissions over the available projection period (2020 to 2050). For the initial federal run, emissions projections were made utilizing the Reference Case from the 2019 AEO report. All other scenario years and pollutant species remained unchanged from their baseline values. The 2.6 scenario was chosen for initial analysis because the federal emissions would have the largest signal (i.e., percent) relative to the other scenarios, each of which have far greater emissions. The results of the initial MAGICC run suggest that 30-plus years of projected federal emissions would raise average global surface temperatures by approximately 0.0158 °C., or 1% of the lower carbon budget temperature target.

* * *

8.0 Climate Change Science and Trends

8.1 Introduction to Climate Science

Climate refers to atmospheric conditions (e.g., temperature, humidity, pressure, precipitation, solar radiation, wind) at a particular location averaged over a long period of time. Climatologists commonly use 30-year averages of variables, such as temperature and precipitation, as benchmarks for historical comparison and climate change assessment.

In addition to characterizing long-term weather, climate reflects the frequency, variability, and extreme ranges of atmospheric variables and phenomena. There are numerous sources of natural climate variability on scales ranging from years to millennia, including volcanic eruptions (e.g., Robock 2000)[26], fluctuating solar irradiance (e.g., Schmidt et al. 2012),[27] and changes to earth's orbit (Milankovitch cycles). There are also many "teleconnections" such as the El Niño Southern Oscillation (ENSO), North Atlantic Oscillation, and Pacific Decadal Oscillation that shape interannual, interdecadal, and multidecadal climate variability. Each of these sources of natural climate variability occur on distinct time scales, some episodic like volcanic eruptions, while teleconnections are cyclical with varying periodicities. Moreover, each source of climate variability produces differing impacts based on region and time of year. For instance, ENSO impacts are more pronounced during winter in the United States, with a strong Pacific Northwest and southwestern United States signal, but no clear impact in the central Rocky Mountains. Teleconnections also do not necessarily produce similar impacts during each occurrence with climate anomalies that differ from typical patterns associated with specific phases of each teleconnection commonly observed. A notable example is the 2015-16 El Niño, which was exceptionally dry in California and relatively wet in the Pacific Northwest, counter to seasonal outlooks and typical El Niño conditions (Cash and Burls 2019)[28]. Multiple modes of atmospheric and oceanic variability introduce tremendous uncertainty in earth's climate on interannual to interdecadal time scales. On longer time scales, GHG concentrations exert a larger influence on earth's climate than the higher frequency oscillations that produce natural interannual to multiyear variability. Because GHG emissions dominate other sources of climate variability on the multidecade to century time scale, climate change models can project future states of Earth's climate based on GHG emissions scenarios.

The American Meteorological Society defines climate change as "any systematic fluctuation in the long-term statistics of climate elements (e.g., temperature, pressure, or wind) that is sustained over several decades or longer" (AMS 2012)[29]. While climate has changed throughout earth's history due to natural forcing, recent climate change is almost entirely the result of increasing GHG concentrations resulting from human activity since the Industrial Revolution.

8.2 Climate Forcing and Feedbacks

The driver for the buildup of heat within the climate system is best described in terms of radiative forcing (RF). The term describes the energy balance (i.e., equilibrium), or the difference between solar radiation absorbed by the Earth and the energy radiated back to space that will occur given the heliophysics of the sun-earth system and the basic laws of thermodynamics. Radiative forcing, given in units of watts per square meter (W m^{-2}), has both positive (+ heating) and negative (- cooling) components, such that altering any of these components will likely cause the climate system to settle into a new equilibrium. GHGs help to contain solar energy loss by trapping longer wave (low energy) radiation emitted from Earth's surface, and thus act as a positive forcing component for which the buildup of these gases has contributed to the current changing state of the climate equilibrium towards warming.

Current ongoing global climate change is caused, in large part, by the atmospheric buildup of GHGs, which may persist for decades or even centuries. The buildup of GHGs such as CO_2, CH_4, N_2O, and fluorinated gases since the Industrial Revolution (1760 to 1840) has substantially increased atmospheric concentrations of these compounds compared to background levels. Several types of activities contribute to the phenomenon of climate change, including emissions of GHGs (especially CO_2 and CH_4) from fossil fuel development, large wildfires, activities using combustion engines, changes to the natural carbon cycle, and changes to radiative forces and reflectivity (albedo). It is important to note that GHGs will have a sustained climatic impact over different temporal scales due to their differences in warming potential and atmospheric lifespans.

Between 1750 and 2011, cumulative anthropogenic CO_2 emissions emitted to the atmosphere were approximately 2,040 ± 310 $GtCO_2$. About 43% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$), while the rest was removed from the atmosphere and stored in natural terrestrial ecosystems (plants and soils – 29%) and in the oceans (28%). Although CO_2 levels in the atmosphere have varied perpetually throughout Earth's history along with corresponding variations in climatic conditions, industrialization and the burning of carbon-based fossil fuel sources have caused CO_2 concentrations to increase measurably, from approximately 280 ppm in 1750 to 413.67 ppm as of March 2020. The rate of increase in CO_2 is unprecedented, at more than 250 times faster than from natural sources after the last Ice Age (NASA 2021)[30]. This fact is demonstrated by data from the Mauna Loa CO_2 monitor in Hawaii that documents atmospheric concentrations of CO_2 going back to 1960, at which point the average annual concentration was recorded at approximately 317 ppm. The record shows that approximately 72% of the increase in atmospheric CO_2 concentration since pre-industrial times (1750) occurred within the last 60 years. The Mauna Loa site also contains updated trend data for CH_4 and N_2O (see Figure 8-1). The trends correspond to an increasing population and rising standards of living and modernization around the globe.

From pre-industrial times to present, emissions from fossil fuel combustion and cement production have released 375 [345 to 405] GtC to the atmosphere (68%), while deforestation and other land use change are estimated to have released 180 [100 to 260] GtC (32%). Concentrations of CO_2, CH_4, and N_2O are now substantially higher than concentrations found in various ice cores dating back to the past 800,000 years. Table 8-1 shows a summary of the anthropogenic changes to atmospheric GHGs since pre-industrial times. The estimated concentrations of CH_4 have more than doubled (722 ppb to 1,874 ppb), while N_2O concentrations have increased by a fifth (270 ppb to 333 ppb).

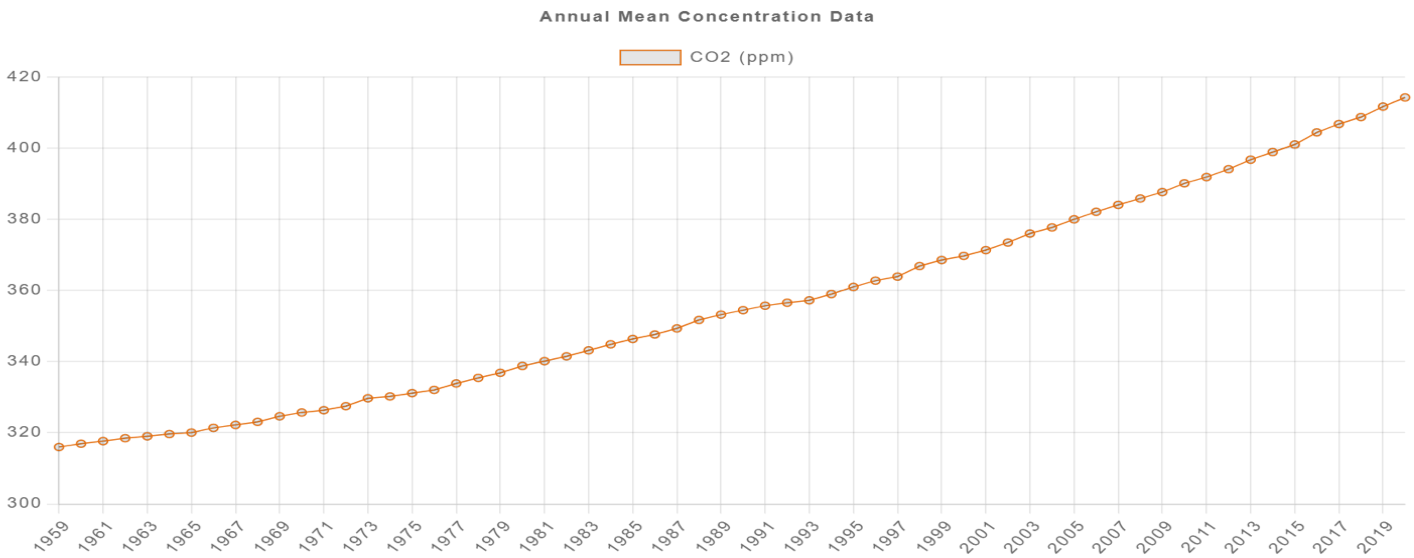


Figure 8-1. Atmospheric GHG Concentrations

Table 8-1. Global Atmospheric Concentration and Rate of Change of Greenhouse Gases

	CO_2 (ppm)	CH_4 (ppb)	N_2O (ppb)
Pre-Industrial Concentration	278	722	270
2020 Atmospheric Concentration	414.2	1,879.3	333
2020 Concentration Relative to Pre-Industrial	149%	260%	123%
Rate of Change over last 10 years (ppm|ppb/yr)	2.39	8.1	0.96

> Source: https://gml.noaa.gov
> ppm = parts per million, ppb = parts per billion.

Each year, the National Oceanic and Atmospheric Administration (NOAA) publishes updates to its Annual Greenhouse Gas Index (AGGI). The AGGI was developed to provide an easily understood standard for expressing the climate-warming influence of long-lived GHGs. Specifically, the AGGI is the ratio of the total direct climate forcing from measured long-lived GHG concentrations compared to the 1990 baseline year (chosen because it is the baseline year for the Kyoto Protocol and the publication year of the first IPCC Scientific Assessment of Climate Change).

The 1990 baseline year is given an AGGI value of 1.0, and the pre-industrial era is given a value of 0.0 (see Figure 8-2) (Lindsey 2020)[31]. The AGGI for 2020 was 1.47 which corresponds to CO_2 equivalents atmospheric concentration of 504 ppm. This represents a 45% increase to climate forcing since 1990 and a 1.8% increase over 2018 levels. While the AGGI does not predict the amount the Earth's climate has warmed, it does provide a measure of the effect of GHG emissions on the climate system.

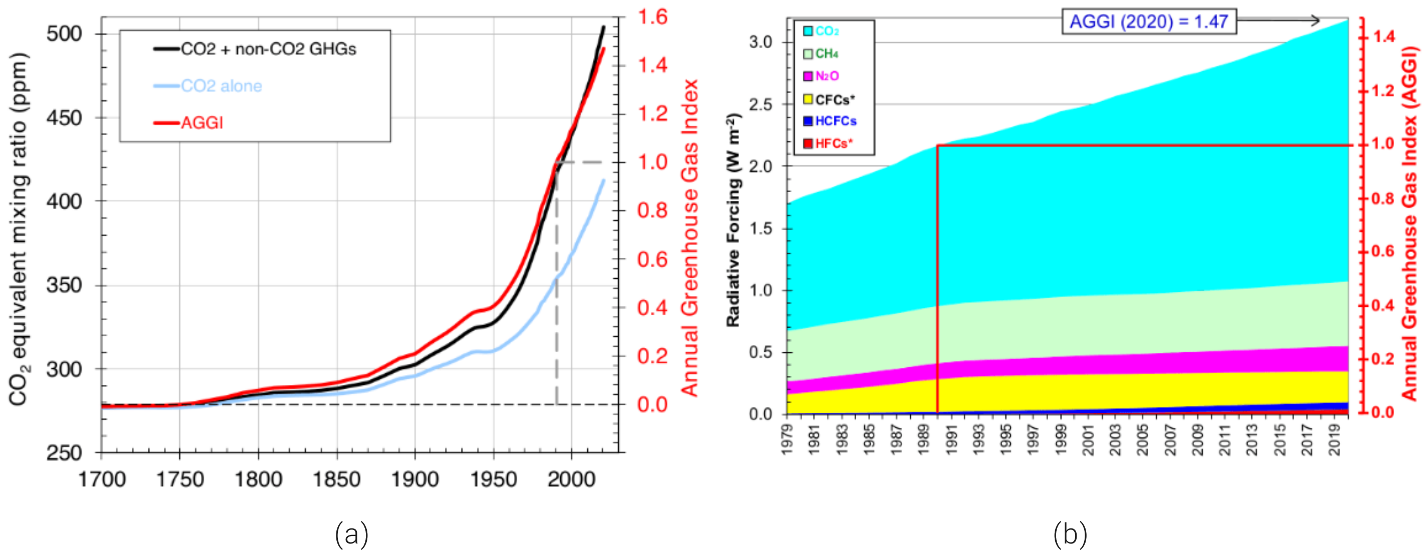


Figure 8-2. 2020 Annual GHG Index

The total anthropogenic RF for 2011 relative to 1750 (i.e., the pre-industrial era) was 2.29 ± 1.04 W m^{-2}, which includes both heating and cooling parameter estimates. For well-mixed GHGs, the total positive forcing is estimated to be 2.83 ± 0.29 W m^{-2}. The largest contribution to total RF since 1750 is caused by the increase in the atmospheric concentration of CO_2. Emissions of CO_2 alone caused an RF of 1.82 ± 0.19 W m^{-2} (64%), while CH_4 caused an RF of 0.48 ± 0.05 W m^{-2} (17%). The data highlights methane's important role as a potent greenhouse gas, given its RF value in relation to its atmospheric loading trend, approximately 556 Tg yr−1 (64% anthropogenic, 36% natural), and relatively short atmospheric lifetime (12 years). N_2O has the third largest forcing of the anthropogenic gases, at 0.17 ± 0.03 W m^{-2} (6%). Collectively, the three GHGs of concern account for approximately 87% of the positive forcing within the climate system.

Earth's climate system is complex and interwoven in ways that are not yet fully understood. There are several known climate feedback mechanisms that add uncertainty in terms of timing (fast and slow feedbacks) and overall sensitivity within the evaluation of the climate system. Sensitivity refers to the amount of positive or negative feedback that occurs in response to a given forcing. The feedbacks and processes connecting RF to a climate response can operate on a large range of time scales. Reaching temperature equilibrium in response to anthropogenic activities (emissions and land use changes) takes decades or longer because some of the climate components—in particular the oceans and cryosphere—are slow to respond due to their large thermal masses and the long-time scale of circulation between the ocean surface and the deep ocean. Some of the latest available climate feedback research indicates that relatively small changes in RF can initiate stronger responses in some feedback components. This suggests that some of these mechanisms, and the climate in general, may have a higher sensitivity than is currently understood. As with the forcing components, there are also positive and negative feedback mechanisms, and there is a relatively large range of uncertainty concerning estimates of the climate sensitivity that leaves the subject open to further investigation. To quote directly from Chapter 8 of the Working Group I contribution to AR5, "In a complex and interconnected system, feedbacks can become increasingly complex, and uncertainty of the magnitude and even direction of feedback increases the further one departs from the primary perturbation, resulting in a trade-off between completeness and robustness, and hence utility for decision-making." Figure 8-3 shows a conceptualized model of the climate and feedback mechanisms and how they interact.

Simplified Conceptual Framework of the Climate System

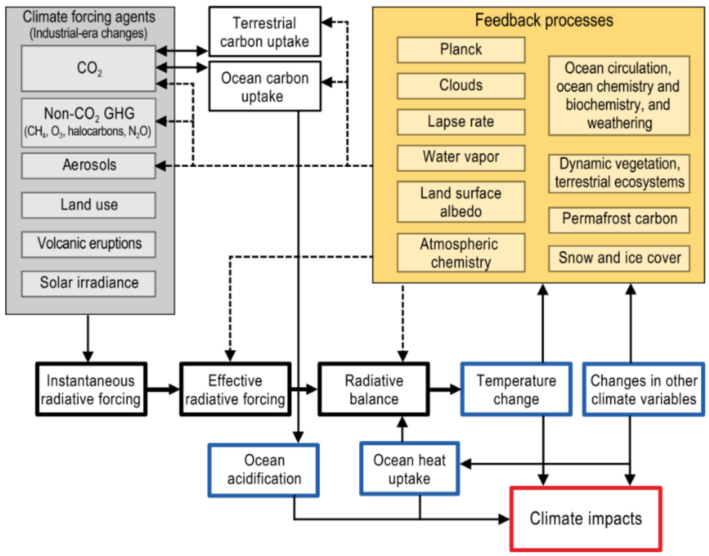


Figure 8-3. Conceptualized Climate System Diagram

8.3 Past and Present Climate Impacts

According to IPCC's climate assessment report: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentration of greenhouse gases have increased." According to IPCC's AR5 report, the globally averaged combined land and ocean surface temperature data, as calculated by a linear trend, show warming of 0.85 ± 0.2 °C over the period 1880 to 2012. A recent study suggests that modern global temperatures are the highest in the last 12,000 years (Bova et al. 2021)[32].

Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] meters. Rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades, due to fluctuations in ocean circulation.

IPCC's report further states that on a global scale, the ocean warming is largest near the surface, and the upper 75 meters warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. Ocean warming has dominated the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. It is virtually certain that the upper ocean (0–700 m) warmed during this period, and it likely warmed between the 1870s and 1971. There is very high confidence that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century by 1.6 [0.8 to 2.4] % per decade for March and April, and 11.7% per decade for June, over the 1967 to 2012 period. There is high confidence that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s, with reductions in thickness and areal extent in some regions. Based on multiple independent analyses of measurements, it is virtually certain that globally the troposphere has warmed, and the lower stratosphere has cooled since the mid-20th century.

The following summary text provides an overview of the highlights from the fourth iteration of the National Climate Assessment (NCA) report. The NCA provides region-specific impact assessments for climate change parameters that are anticipated to occur throughout this century. The global climate continues to change rapidly compared to the pace of the natural variations in climate that have occurred throughout the

Earth's history. Trends in globally averaged temperature, sea level rise, upper-ocean heat content, land-based ice melt, arctic sea ice, depth of seasonal permafrost thaw, and other climate variables provide consistent evidence of a warming planet. These observed trends are robust and have been confirmed by multiple independent research groups around the world (very high confidence). Many lines of evidence demonstrate that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Formal detection and attribution studies for years 1951 to 2010 find that the observed global mean surface temperature warming lies in the middle of the range of likely human contributions to warming over that same period. Natural variability, including El Niño events and other recurring patterns of ocean–atmosphere interactions, impact temperature and precipitation over months to years, especially at regional scales. The global influence of natural variability, however, is limited to a small fraction of observed climate trends over decades (very high confidence). Studies found no convincing evidence that natural variability can account for the amount of global warming observed over the industrial era. For the period extending over the last century, there are no convincing alternative explanations supported by the extent of the observational evidence. Solar output changes and internal variability can only contribute marginally to the observed changes in climate over the last century, but no convincing evidence for natural cycles in the observational record can explain the observed changes in climate (very high confidence).

The frequency and intensity of extreme heat and heavy precipitation events are increasing in most continental regions of the world, and these trends are consistent with expected physical responses to a warming climate. Climate model studies are also consistent with these trends, although models tend to underestimate the observed trends, especially for the increase in extreme precipitation events (very high confidence for temperature, high confidence for extreme precipitation). The frequency and intensity of extreme high temperature events are virtually certain to increase in the future as global temperature increases (high confidence). Extreme precipitation events will very likely continue to increase in frequency and intensity throughout most of the world (high confidence). Observed and projected trends for some other types of extreme events, such as floods, droughts, and severe storms, have more variable regional characteristics.

The annual average temperature over the contiguous United States has increased by 1.2ºF (0.7°C) over the last few decades and by 1.8°F (1°C) relative to the beginning of the last century. Additional increases in annual average temperature of about 2.5°F (1.4°C) are expected over the next few decades regardless of future emissions, and increases ranging from 3°F to 12°F (1.6°–6.6°C) are expected by the end of century, depending on whether the world follows a higher or lower future scenario, with proportionally greater changes in high temperature extremes. At the regional scale, each National Climate Assessment (NCA) region experienced increasing temperatures between 1901–1960 and 1986–2016. The largest changes were in the western half of the United States, where average temperature increased by more than 1.5°F (0.8°C) in Alaska, the Northwest, the Southwest, and in the Northern Great Plains. Over the entire period of record, the Southeast has had the least warming due to a combination of natural variations and human influences; since the early 1960s, however, the Southeast has been warming at an accelerated rate. Over the past two decades, the number of high temperature records recorded in the United States far exceeds the number of low temperature records. The length of the frost-free season has increased in each NCA region since the early 1900s. The frequency of cold waves has decreased since the early 1900s, and the frequency of heat waves has increased since the mid-1960s.

Annual average precipitation has increased by 4% since 1901 across the entire United States, with strong regional differences: increases over the Northeast, Midwest, and Great Plains and decreases over parts of the Southwest and Southeast consistent with the human-induced expansion of the tropics. The frequency and intensity of heavy precipitation events across the United States have increased more than average precipitation.

8.4 BLM Fossil Fuel States Climate Change Impacts

The climate change indicators, impacts, and trends specific to states where the BLM conducts most of its fossil fuel authorizations are subsequently described. For each state, precipitation and temperature data from the NOAA's climate division dataset (Vose et al. 2014)[33] are presented to document climate trends. Data extending back to 1895 are available for each state in the contiguous United States while the period of record for Alaska begins in 1925. Detailed narratives for each state's current climate conditions can be found at NOAA with additional information provided by the Western Regional Climate Center.

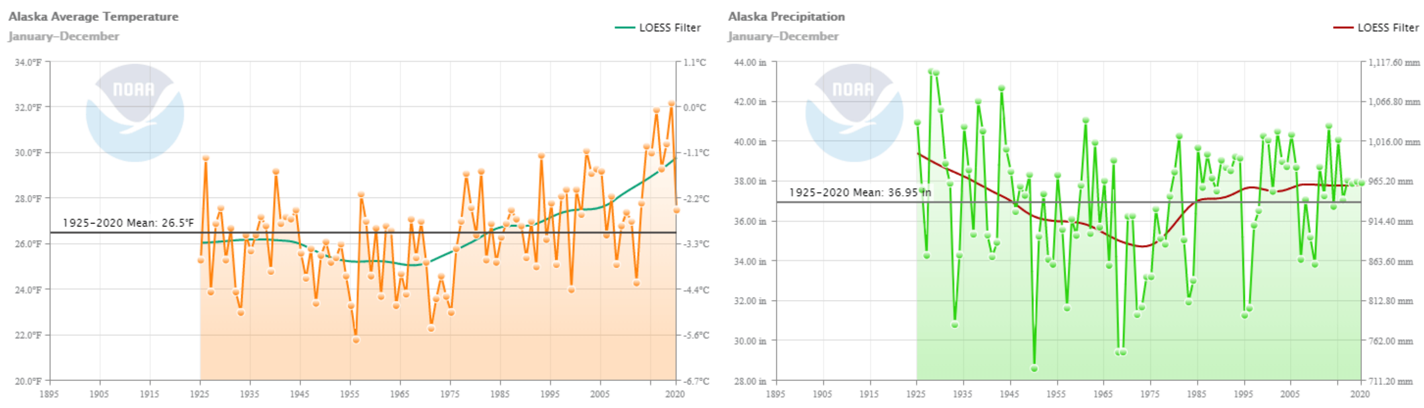
Alaska

From 1925 to the mid-1970s, the statewide annual average temperature decreased by about 1°C. A major climate shift in the Pacific Ocean during the 1976-77 winter season, detailed extensively by Miller et al. (1994)[34] produced many environmental impacts throughout the Pacific Basin including significant changes in Alaskan climatology as reported by Hartmann and Wendler (2005)[35]. Since the Pacific Ocean shift of 1976-77, the statewide annual average temperature increased by 2.5°C to 3°C with the four warmest years on record in Alaska observed since 2014 (Figure 8-4). Most of the warming has occurred in the winter and spring seasons, and the least amount in fall. Summer temperatures have been well above average since 1990 and winter temperatures have been above average since 2002. Some recent warming has been linked to the Pacific Decadal Oscillation, which is a major control on Alaskan climate. However, the most recent 10-year period (2011-2020) was over 1°C warmer than any 10-year period in the 20th century. Starting in the 1990s, high temperature records occurred three times as often as record lows, and in 2015, nine times as frequently. However, temperature trends across the state vary considerably with the most warming observed in the North Coast, West Coast, Central Interior, and Bristol Bay climate divisions. Since the 1970s, Arctic and boreal regions in Alaska have experienced rapid rates of warming and thawing of permafrost.

There is no clear trend in statewide precipitation (Figure 8-4), though in the past three decades, precipitation in the West Coast, Northeast Interior, and Central Panhandle climate divisions averaged about 10% higher than the 1925-1999 mean. As with average precipitation, the occurrence of extreme precipitation events are highly variable and are both regionally and seasonally dependent. Most of Alaska has seen an increase in extreme precipitation events (the heaviest one percent of 3-day precipitation totals) since the mid-20th century. However, there is no statewide average trend in the number of days with precipitation exceeding 1 inch since 1950, and the highest values occurred in the 1930s.

Late summer Arctic sea ice extent and thickness has decreased substantially in the last several decades, and the ice volume is approximately half of that observed prior to satellite monitoring in 1979. Since the early 1980s, annual average arctic sea ice extent has decreased between 3.5% and 4.1% per decade, and September sea ice extent, which is the annual minimum extent, has decreased between 10.7% and 15.9% per decade. The lowest minimum Arctic sea ice extent occurred in 2012. Arctic sea ice plays a vital role in the climate of Alaska, the lives of its inhabitants, and the functionality of its ecosystems. Warming linked to ice loss influences atmospheric circulation and precipitation patterns, both within and beyond the Arctic. With the late-summer ice edge located farther north than it used to be, storms produce larger waves and cause more coastal erosion. A significant increase in the number of coastal erosion events has been observed as the protective sea ice embankment is no longer present during the fall months. In response to the increased erosion, several coastal communities are seeking to relocate.

Glaciers continue to melt in Alaska, with an estimated loss of 75 ± 11 gigatons (Gt) of ice volume per year from 1994 to 2013, 70% of which is coming from land-terminating glaciers; this rate is nearly double the 1962–2006 rate. Melting glaciers are likely to produce uncertainties for hydrologic power generation, which is an important resource in Alaska.



(a) (b)

Figure 8-4. AK Temperature and Precipitation Records

California

The average annual temperatures in California have increased by nearly 3°F since the beginning of the 20th century (Figure 8-5). The years 2014 and 2015 were the first and second warmest, respectively, in the 126-year record, and the most recent 10-year period (2011-2020) was the warmest on record. Since 1995, California has experienced a below normal number of cold nights and its highest number of very warm nights over the historical record. The record warmth in 2014 and 2015, in combination with multiple years of below average precipitation including the driest year (Figure 8-5) led to the most severe drought of the past 1,200 years (Griffin and Anchukaitis 2014)[36].

While there is no long-term trend in statewide precipitation (Figure 8-5), 2013 and 2020 were the driest and third driest years, respectively, in the 126-year record. Like precipitation, the state's snowpack varies greatly from year to year. During the SNOTEL monitoring era, which begins around 1980, snowpack has decreased slightly in the state's major river basins. According to data provided by the USDA's Natural Resources Conservation Service (NRCS), statewide April 1 snowpack has averaged about 10% lower during the first two decades of the 21st century as compared to the last two decades of the 20th century, with 2015 likely featuring the lowest snowpack in the Sierra Nevada in the last 500 years (Belmecheri et al. 2015)[37].

Many coastal resources in the state have been affected by sea level rise, ocean warming, reduced ocean oxygen, and ocean acidification—all impacts of human-caused climate change. At the Golden Gate Bridge in San Francisco, sea level rose 9 inches (22 cm) between 1854 and 2016, and in San Diego, sea level rose 9.5 inches (24 cm) from 1906 to 2016.

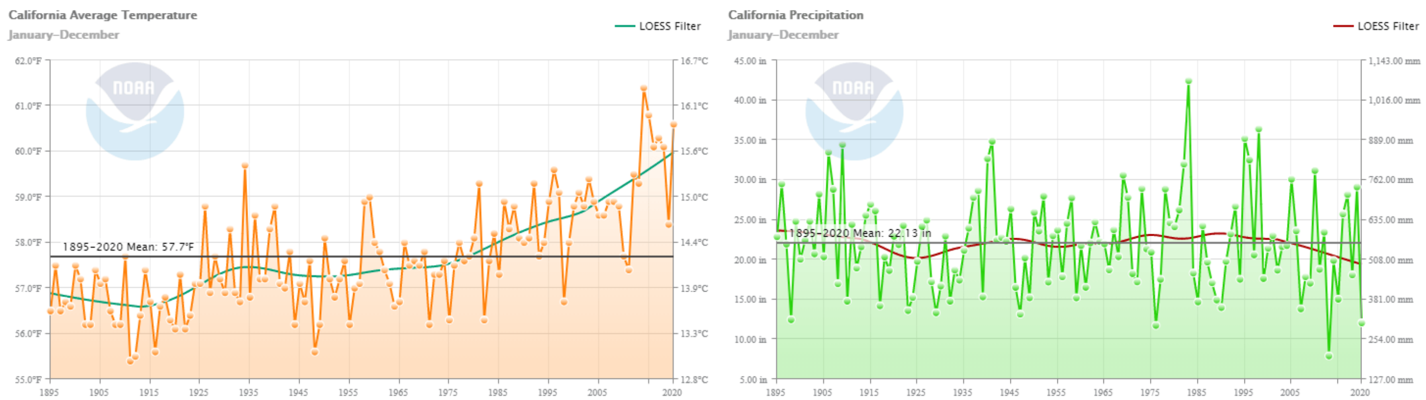


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Figure 8-5. CA Temperature and Precipitation Records

Colorado

Since the start of the 20th century, the average annual temperature in Colorado increased by approximately 2.5°F (Figure 8-6). Six of the eight hottest years in the state's recorded history have occurred since 2012, and the most recent 10-year period (2011-2020) was the hottest yet observed. While temperatures have increased statewide, the Colorado Basin (Colorado Climate Division 2) has warmed by nearly twice as much as either the Arkansas Basin (Colorado Climate Division 1) or the Rio Grande Basin (Colorado Climate Division 5). In addition to the overall trend of higher average temperatures, the state has experienced an above average number of very hot days (days with a maximum temperature exceeding 95°F) and a decrease in the number of very cold nights (days with a minimum temperature below 0°F) since 1990. Warming has occurred in all seasons and has been observed throughout the state. Daily minimum temperatures increased more than daily maximum temperatures. Increased temperatures have contributed to earlier snowmelt and peak runoff timing during spring by 1 to 4 weeks. The growing season (i.e., frost-free days) has increased by nearly 3 weeks since 1991 relative to the 1901 to 1960 average.

Long-term average annual precipitation has been variable, though Colorado has generally experienced above average fall precipitation since 1980 and below average spring precipitation since 2000. Unlike many areas of the United States, Colorado has not experienced an upward trend in the frequency of extreme precipitation events. Drought reconstructions from tree rings indicate that droughts are a frequent occurrence in Colorado, and episodes more severe than any in the historical record have occurred in the more distant past.

Despite historically low snowpack in 2012, there is no long-term trend in April 1 snowpack water at Berthoud Pass, which has one of the state's longer snow course sampling histories. However, there is considerable site-specific variability among Colorado snow course locations, with some indicating no long-term trend while others show a significant decrease in April 1 snowpack. Snowpack data from the NRCS show that during the most recent 40 years covered by SNOTEL data, year-to-year variability in basin-specific and statewide April 1 snowpack is large, though in general, snowpack has been slightly lower in the most recent 20-year period.

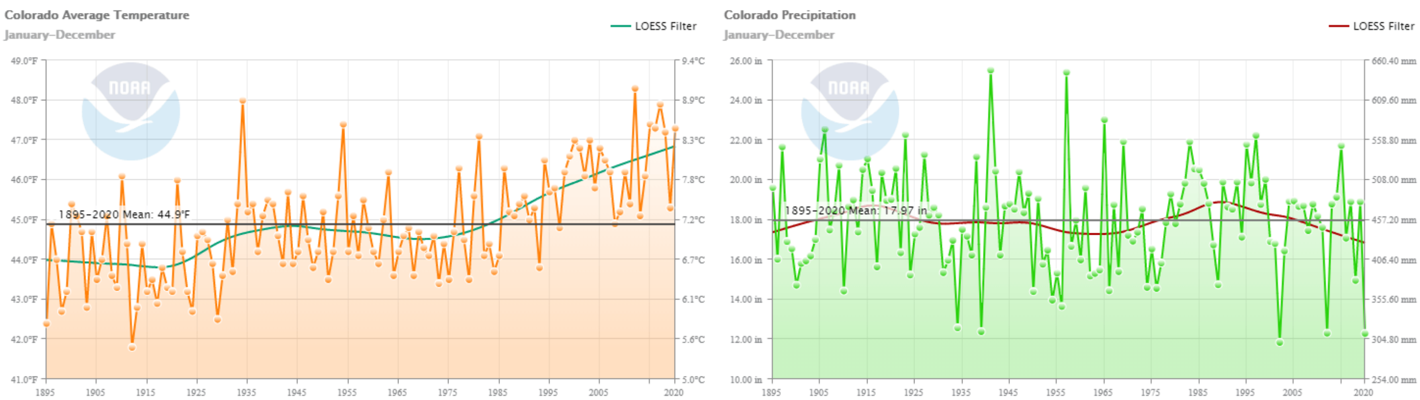

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Figure 8-6. CO Temperature and Precipitation Records

<u>Northern Great Plains (Montana, North Dakota, and South Dakota)</u>

Since the start of the 20th century, Montana and the Dakotas have warmed by about 2.5°F. Since 1981, 8 and 9 of the hottest years on record have occurred in the Dakotas and Montana, respectively. While temperatures have increased in all seasons, the largest increase has occurred in winter and spring. For example, over the past 130 years, winter temperatures in North Dakota have increased by 4.4°F per century, more than three times as much as the summer trend of 1.4°F per century. Warmer temperatures have extended the growing season by as much as 30 days in the northern Great Plains.

There is no clear long-term trend in Montana precipitation, but in the Dakotas, annual precipitation amounts have increased, and rainstorms are becoming more intense. Over the last 50 years in the Great Plains, the amount of rain falling during the wettest 4 days of the year increased by approximately 15%. Increasing rainfall could benefit some farms but also may increase the risk of flooding.

Despite warming temperatures, NRCS snowpack data show that average April 1 snow-water equivalents in Montana has not changed during the SNOTEL era. However, since 1955, longer term snow course data indicate a significant decrease in Montana's April 1 snowpack (Mote et al. 2018)[38].

Rising temperatures and recent droughts have killed many trees by drying out soils, increasing the risk of forest fires, or enabling outbreaks of forest insects. In the coming decades, the changing climate is likely to decrease the availability of water in Montana, affect agricultural yields, and further increase the risk of wildfires.

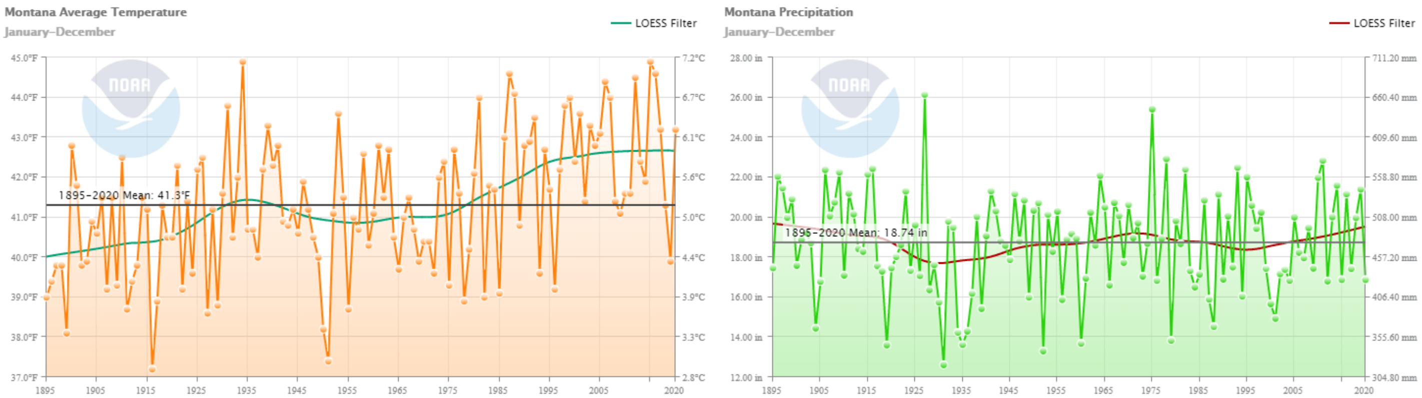

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Figure 8-7. MT Temperature and Precipitation Records

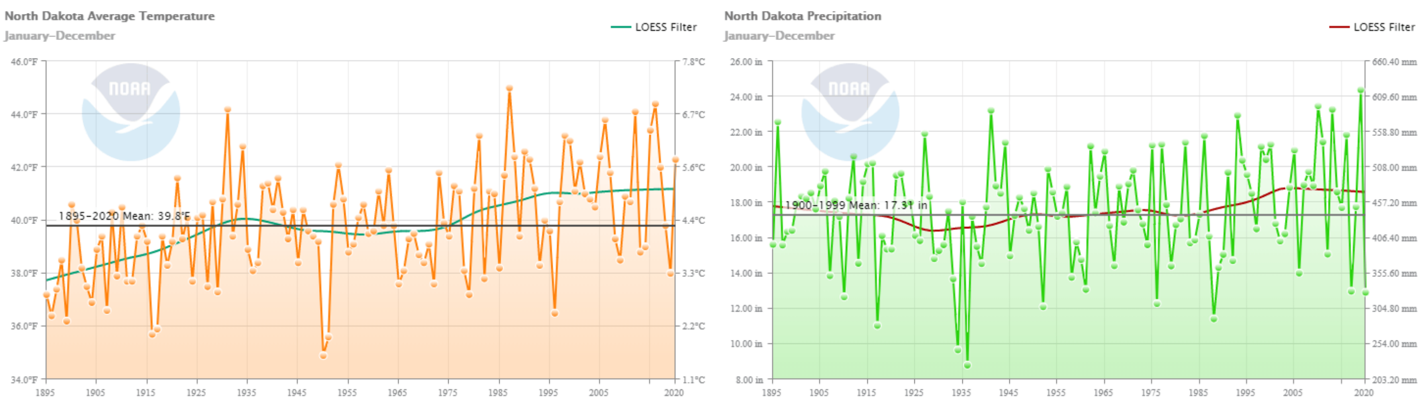

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Figure 8-8. ND Temperature and Precipitation Records

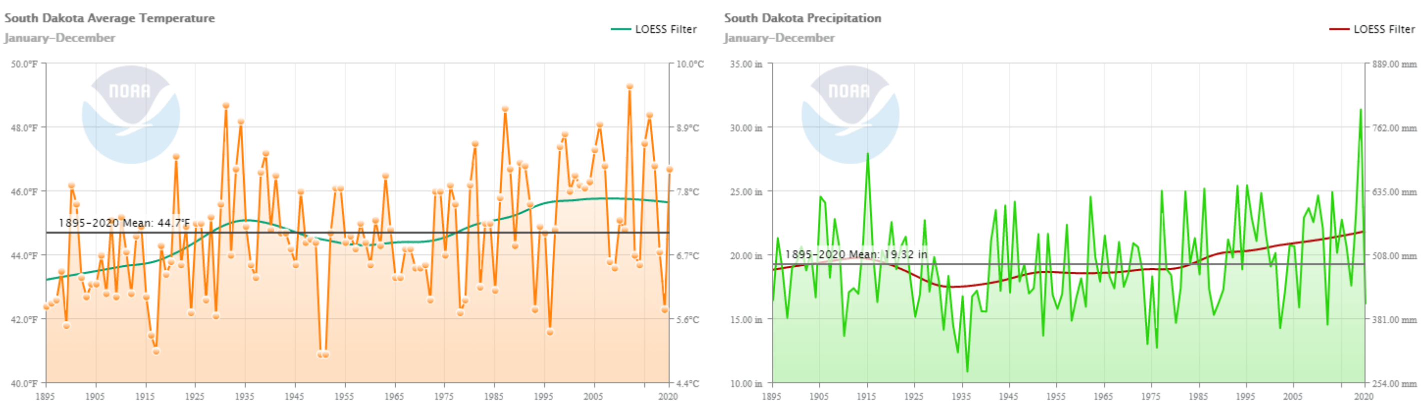

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Figure 8-9. SD Temperature and Precipitation Records

New Mexico

From 1895 to the end of the 1970s, there was no trend in New Mexico mean annual temperature, but since 1980, the mean annual temperature increased by approximately 2.5°F (Figure 8-10). The last decade (2011-2020) was the warmest on record for the state, and the 3 hottest years observed each occurred since 2012. Temperatures have increased the most in the central and southeastern portions of the state while the northeastern plains and Mogollon Rim have warmed by about half as much (Vose et al. 2017)[39]. Along with higher mean temperatures, much of the state has seen increases in the number of extremely hot days (maximum temperature at or above 100°F), especially on the eastern plains.

There is large interannual and interdecadal variability in New Mexico precipitation (Figure 8-10). While 2020 was the second driest year on record and the most recent decade (2011-2020) was the driest since 1955-1964, there is no long-term trend in mean annual precipitation. Statewide annual precipitation has ranged from a high of 26.57 inches in 1941 to a low of 6.58 inches in 1956. Unlike many areas of the United States, there has been no increase in the frequency of extreme precipitation events (days with an inch or more of precipitation) in New Mexico. While the average number of such events between 2015 and 2018 period was the highest on record, it is too short a period to constitute a trend. Drought reconstructions from tree rings indicate that droughts are a frequent occurrence in New Mexico, and episodes more severe than any in the recent historical record have occurred in the more distant past.

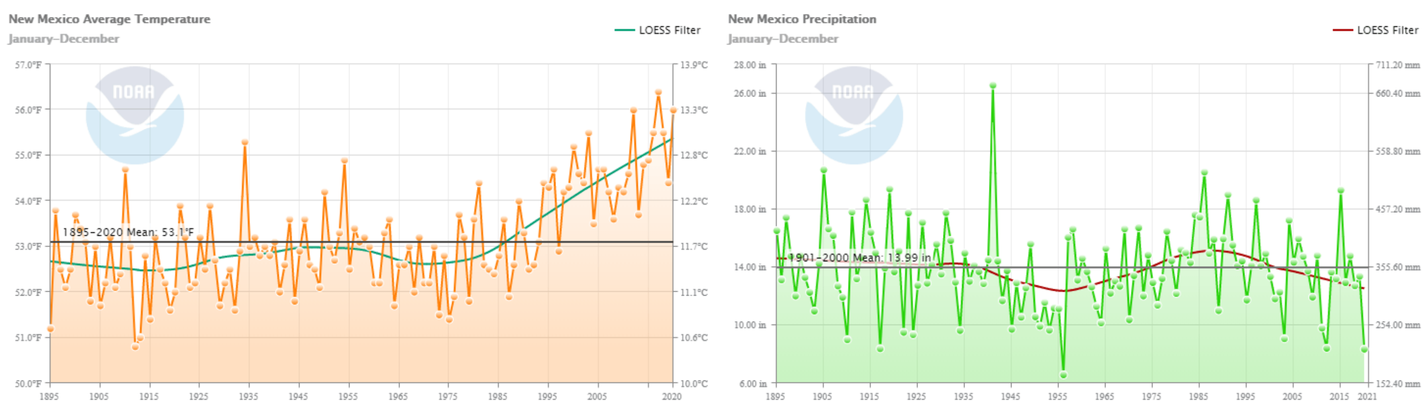

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Figure 8-10. NM Temperature and Precipitation Records

Utah

The early 21st century has been the warmest period on record for Utah (Figure 8-11). Since 1895, temperatures have been increasing 0.2ºF to 0.3 ºF per decade in each of Utah's seven climate divisions. The period from 2000 to 2004 had the largest number of extremely hot days with maximum temperature at or above 100°F in the historical record. In addition to the overall trend of higher temperatures, the state has experienced a marked increase in the number of very warm nights (minimum temperature at or above 75°F) and a decrease in the number of very cold nights (minimum temperature at or below 0°F) since 1990. While 2020 was the driest year on record for Utah and 21st century precipitation has averaged a few percent below the long-term mean across Utah, there is no statistically significant trend in precipitation for the state or in any climate division with natural variability resulting in both wetter and drier periods than observed in the past two decades (Figure 8-11). As the state has warmed, the percentage of precipitation falling as snow during the winter has decreased, as has snow depth and snow cover.

April 1 snowpack across the state has gradually decreased in the past 40 years with 2011-2020 average statewide snowpack approximately 20% lower than that observed between 1981-1990. Utah frequently experiences droughts. Since snowmelt from the snowpack provides water for many river basins, abnormally low winter and spring precipitation is often the trigger for drought conditions. In 2012, Utah experienced one of its driest springs since records began in 1895, resulting in severe drought conditions in areas across the entire state. The historical record indicates periodic occurrences of extended wet and dry periods. Dry conditions since 2000 have resulted in near-record-low water levels in the Great Salt Lake.

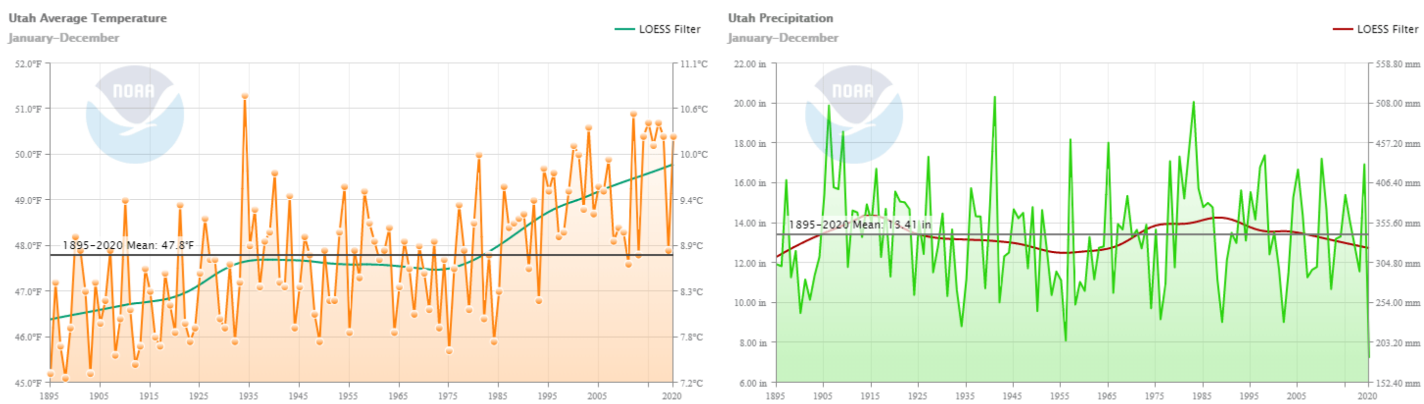

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Figure 8-11. UT Temperature and Precipitation Records

Wyoming

The 21st century has been the warmest period on record for Wyoming, with a net warming of 1.4°F since the beginning of the 20th century (Figure 8-12). Three of the four hottest years on record have occurred since 2012, with that year the hottest in the 126-year observational period. Temperature increases have been observed in all seasons. Since 1995, winter and summer temperatures have averaged 1.9°F and 1.2°F above the historical average, respectively. The state has experienced an above average frequency of very hot days (days with maximum temperature above 95°F) since 2000. Wyoming rarely experiences warm nights (days with minimum temperatures above 70°F), but the early part of the 21st century has seen an above average number of such nights. In addition to the overall trend of higher average temperatures, the state has experienced a below average number of very cold days (days with maximum temperatures below 0°F) since 2000.

There is no long-term trend in statewide annual mean precipitation (Figure 8-12), though 2012 was the driest year on record and 2020 the fifth driest on record. The driest multiyear periods were in the 1930s, 1950s, and 2000s, and the wettest in the 1940s and 1990s. The driest 5-year period was 1931–1935 and the wettest was 1995–1999. Unlike many other areas of the western United States, April 1 snowpack has remained relatively constant over the past 40 years. The median statewide April 1 snowpack between 1981-2000 is the same as that observed during the most recent 10-year period (2011-2020).

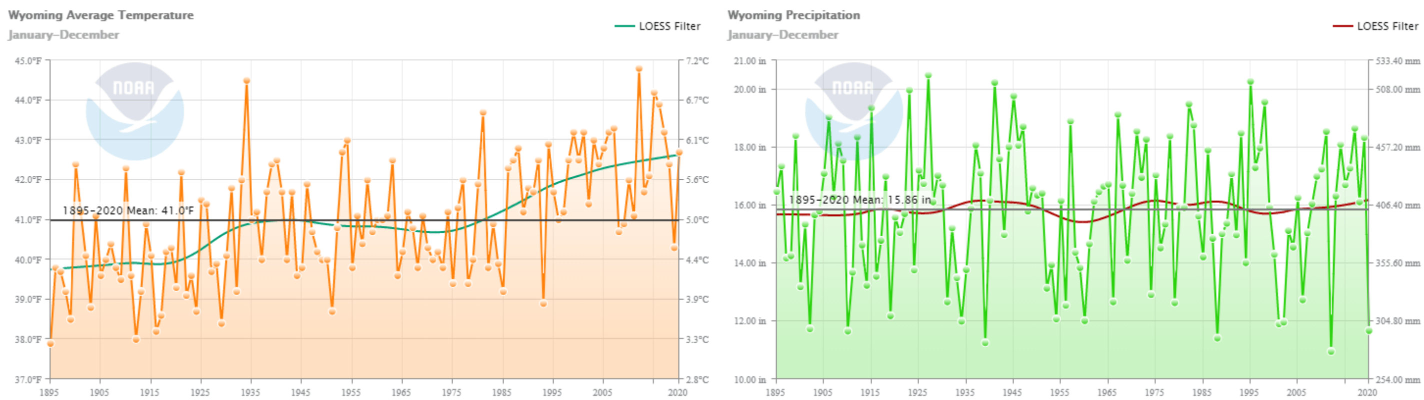

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Figure 8-12. WY Temperature and Precipitation Records

* * *

9.0 Projected Climate Change

9.1 Representative Concentration Pathways

The current understanding of the climate system comes from the cumulative results of observations, experimental research, theoretical studies, and model simulations conducted by thousands of scientists from all over the world. Climate change is fundamentally a cumulative phenomenon, global in scope, and all GHGs contribute incrementally to climate change regardless of scale or origin. The multitude of interwoven natural systems and feedback mechanisms that contribute to climate variability over the entirety of Earth further complicate analysis.

Climate scientists provide analysis by modeling changes to these systems in response to a range of global emissions scenarios known as Representative Concentration Pathways (RCPs). The RCPs are not fully integrated scenarios of climate feedback, policy, emissions limits, thresholds, or socioeconomic projections, but rather a consistent set of cumulative emissions projections out to year 2100 of only the components of radiative forcing that are meant to serve as input for climate and atmospheric chemistry modeling. There are four scenarios that climate scientists have used for assessment in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Figure 9-1).

- *RCP2.6* - A low emissions pathway that is representative of scenarios that lead to very low atmospheric GHG concentrations. Radiative forcing levels reach a peak around 3.1 W/m^2 by mid-century, returning to 2.6 W/m^2 by 2100. To reach these radiative forcing levels, global GHG emissions are reduced substantially over time. This scenario also assumes there will be “negative emissions” starting in 2080, with more carbon being removed from the atmosphere than is emitted. The aggregate global emissions of this pathway is approximately 1,715.7 GtCO2e (2018 - 2100). CO_2 alone represents 54.2% of the total contributing emissions, and 81.5% of the total CO_2 emissions are attributable to fossil fuel use.
- *RCP4.5* - Stabilization scenario where total radiative forcing stabilizes at 4.5 W/m^2 before 2100 by employment of a range of technologies and strategies for reducing GHG emissions. This pathway forecasts global emissions increasing until about 2040, and then declining starting in 2050. The aggregate emissions of this pathway is approximately 3,728.6 GtCO2e (2018 - 2100). CO_2 alone represents 67% of the total contributing emissions, and 98.2% of the total CO_2 emissions are attributable to fossil fuel use.
- *RCP6.0* Stabilization scenario where total radiative forcing stabilizes at of 6.0 W/m^2 after 2100 by employment of a range of technologies and strategies for reducing GHG emissions. Emissions of CO_2 grow steadily until 2080 before declining. The cumulative emissions of this pathway are approximately 5,380.2 $GtCO_2e$ (2018 - 2100). CO_2 alone represents 74.3% of the total contributing emissions and, 101.1% of the total CO_2 emissions are attributable to fossil fuel use. Please note, the Land Use Change (LUC) CO_2 emissions in this scenario are negative at about the mid-century mark, which produces data showing fossil fuel emissions that are greater than the total emissions (which include the negative LUC values).
- *RCP8.5* - Pathway scenario with increasing emissions over time that leads to very high GHG concentration levels and radiative forcing of 8.5 W/m^2 in 2100. This pathway assumes emissions trajectories follow historical growth and assumes no climate policies are enacted to reduce

emissions. The aggregate emissions of this pathway are approximately 9,227.7 GtCO2e (2018 - 2100). CO_2 alone represents 72.3% of the total contributing emissions, and 97.8% of the total CO_2 emissions are attributable to fossil fuel use.

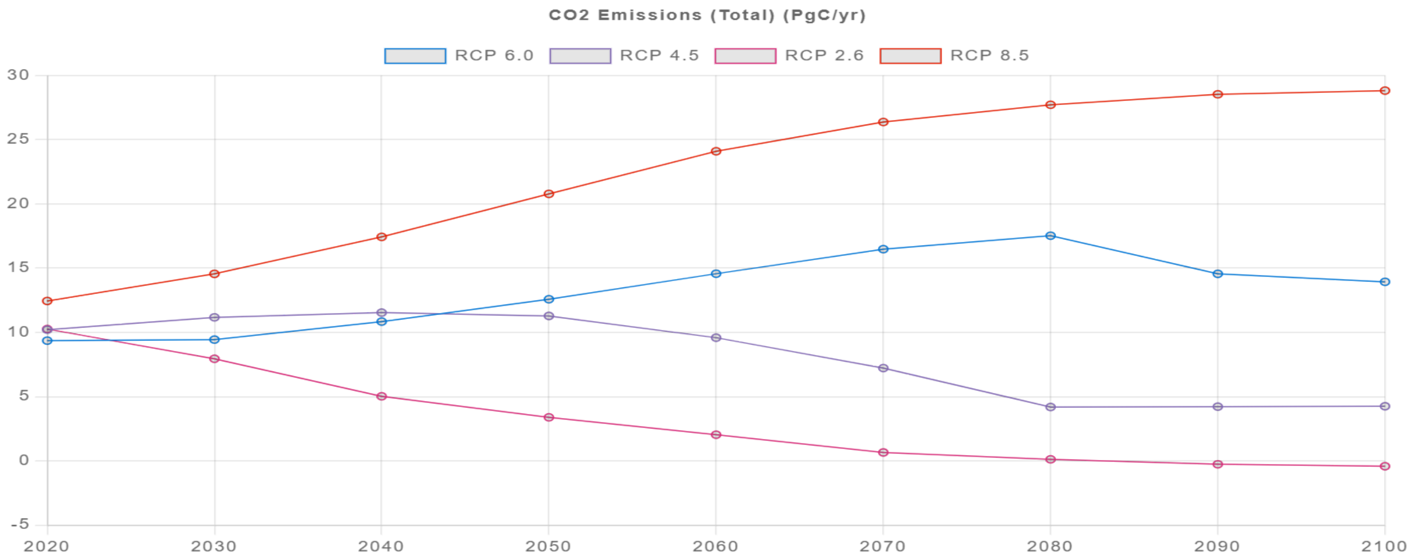


Figure 9-1. RCP Data Time Series - CO2 Emissions

> Source: [RCP Database]

The future climate equilibrium is dependent upon warming caused by past anthropogenic emissions, future anthropogenic emissions, and natural variability. Global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four modeled RCPs and will likely be in the range of 0.3°C to 0.7°C (medium confidence). The projection assumes no major volcanic eruptions, changes in natural emissions sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By 2050, the magnitude of the projected climate change is substantially affected by the overall emissions path along which the world is tracking. It should be noted that according to the IPCC, only emissions projections following the lowest concentration pathway (RCP2.6) result in an estimated mean increase in global average temperatures below 2°C. Equally important, IPCC scientists project warming will continue beyond 2100 under all RCP scenarios except for RCP2.6.

The projected increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0, and 2.6°C to 4.8°C under RCP8.5. As global mean surface temperature increases, it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales. It is also very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur due to the inherent variability within the climate system. Changes in precipitation patterns will not be uniform, but in general, scientists expect arid regions to become drier and wetter areas to experience frequent exceptional precipitation events. Oceans will continue to warm, with the greatest impacts occurring at the surface of tropical and northern hemisphere subtropical regions. Models also predict ocean acidification will increase for all RCP scenarios, where surface pH can be expected to decrease by 0.06 to 0.07 (15 to 17%) for RCP2.6 and 0.14 to 0.15 (38 to 41%) for RCP4.5. Year-round reductions in Arctic sea ice are projected for all RCP scenarios, and it is virtually certain that near-surface (upper 3.5 m) permafrost extent at high northern latitudes will be reduced (37% - RCP2.6 to 81% - RCP8.5) as the global mean surface temperature increases. Global mean sea level rise will very likely continue at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will likely be in the range of 0.26 to 0.55 m for RCP2.6 and of 0.45 to 0.82 m for RCP8.5. It is very likely that the sea level will rise in more than 95% of the ocean area, where about 70% of coastlines worldwide would experience a sea level change within ±20% of the global mean.

9.2 Shared Socioeconomic Pathways

In preparation for the IPCC's Sixth Assessment Report (AR6), the climate science research community, economists, and energy systems modelers developed a new range of “pathways” that examine how global society, demographics, and economics might influence future climate impacts, vulnerabilities, adaptation, and mitigation over the next century. The scenarios are collectively known as the Shared Socioeconomic Pathways (SSPs). These new scenarios are being used to inform the next round of climate modeling that is being incorporated into AR6. The RCPs and SSPs are meant to complement each other. The RCPs set pathways for GHG concentrations and the potential amount of radiative forcing and warming the world may experience by the end of the century. The SSPs explore how reductions in emissions will, or will not, be achieved and can therefore be thought of as potential mitigation alternatives.

There are five basic SSP narratives[40] that were developed. The SSP scenarios provide a range of plausible trends (Figure 9-2) that could shape future society and include the following:

- *SSP1 (Low challenges to mitigation and adaptation)* – The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Consumption is oriented toward low material growth and lower resource and energy intensity.
- *SSP2 (Medium challenges to mitigation and adaptation)* - The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress and others falling short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements, and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly, and challenges to reducing vulnerability to societal and environmental changes remain.
- *SSP3 (High challenges to mitigation and adaptation)* - A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. Policies shift over time to become increasingly oriented toward national and regional security issues. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time. Population growth is low in industrialized and high in developing countries. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

- *SSP4 (Low challenges to mitigation, high challenges to adaptation)* - Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor intensive, low-tech economy. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas.
- *SSP5 (High challenges to mitigation, low challenges to adaptation)* - This world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy, while global population peaks and declines in the 21st century. Local environmental problems like air pollution are successfully managed. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary.

Both SSP1 and SSP5 consider optimistic scenarios for human development with substantial investments in education, rapid economic growth, and technology. They differ in that SSP5 assumes that development is driven by fossil fuel energy, while in SSP1 there is a shift towards sustainable practices and sustainable development. Global markets are increasingly integrated. There are also strong investments in health, education, and renewable energy sources. The SSP2 scenario represents a “middle of the road” path that follows historical development trends throughout the 21st century. While SSP3 and SSP4 present less optimistic economic and social development scenarios, with little investment in education or health in poorer countries coupled with a fast-growing population and increasing inequalities. Each SSP has a baseline scenario that describes future developments in the absence of new climate policies, beyond those already in place today. The SSPs can then be combined with various emission mitigation objectives to identify how each of the different RCPs can be achieved.

To understand how the SSPs relate to different levels of warming under the RCP scenarios, six different integrated assessment models (IAMs) were used. The IAMs produce an estimate of the GHG emissions that would occur based on socioeconomic factors outlined in the SSPs. The resulting emissions were then used as inputs for the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) to provide estimates of atmospheric GHG concentrations and future warming. In addition to the four RCP’s analyzed in AR5, three additional RCPs representing radiative forcing of 1.9, 3.4, and 7.0 W/m^2 were evaluated to expand the range of emissions mitigation targets. The RCP1.9 represents a pathway that limits warming to 1.5°C. The combination of five SSPs and six of the RCPs is shown in Figure 9-1 (a). Each box in the slide shows the number of models that were able to successfully reach the RCP target, out of the total number of models available for a given SSP. For example, the “3/4” in the SSP5 / RCP2.6 cell means that four IAMs tried to achieve RCP2.6 in an SSP5 world, but only three of the models could find a solution. The other model could not either reduce emissions fast enough or generate sufficient negative emissions. Similarly, only SSP5 could generate scenarios that reached RCP8.5 levels of radiative forcing, while emissions were too low in other SSP baselines. This research shows that some mitigation and adaptation to climate change is much easier under some SSP scenarios than others and not all SSPs are compatible with RCPs that limit warming to 1.5°C or 2°C above pre-industrial levels. However, even though not all the IAMs find a viable solution for scenarios that limit warming below 1.5°C or 2°C, it does not necessarily mean that these scenarios are impossible. Models are imperfect and cannot foresee all changes that will happen over the next century.

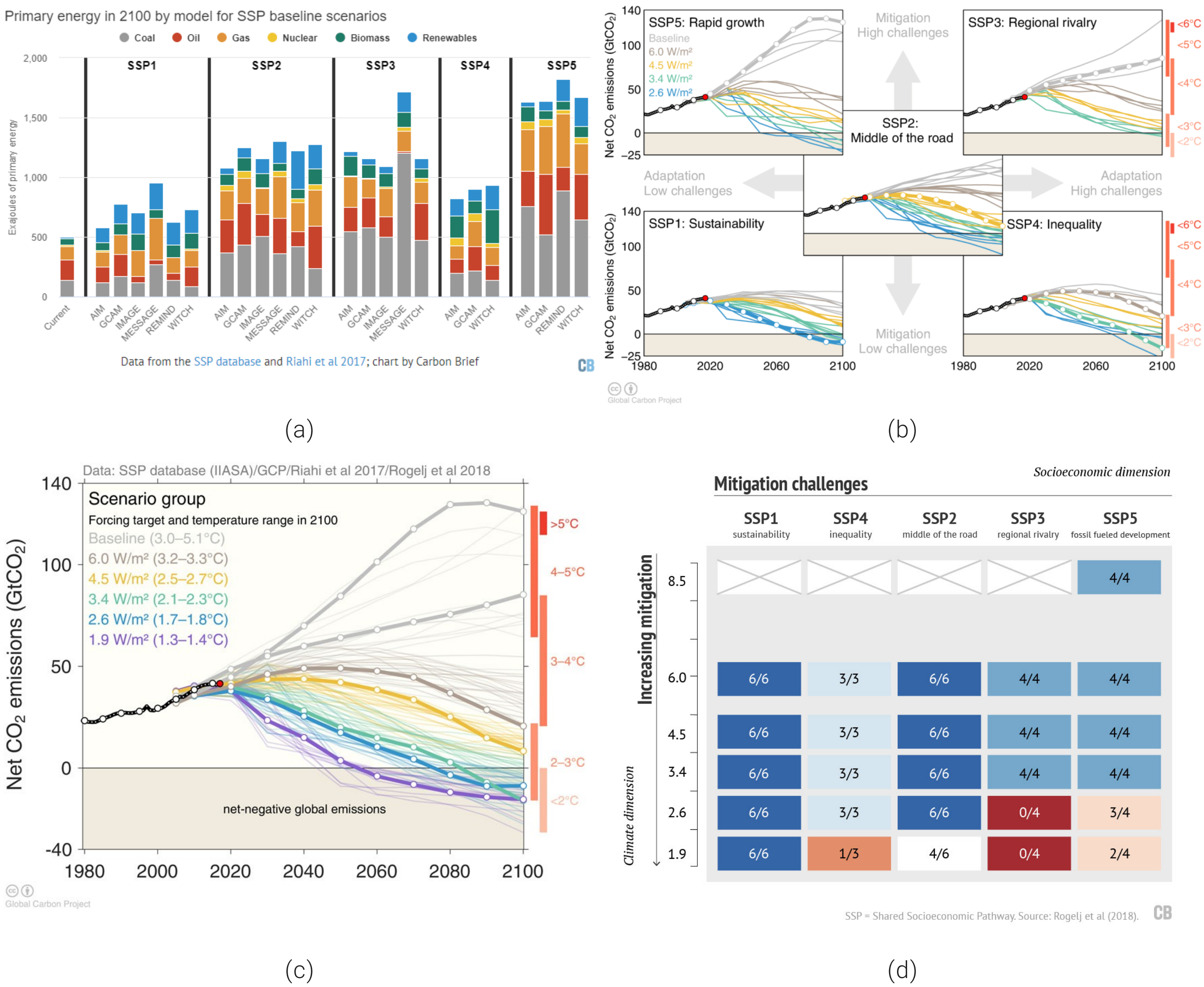


Figure 9-2. Shared Socioeconomic Pathways

(a) - Global primary energy use by fuel type in 2100 in exajoules (EJ) for baseline scenarios in each IAM and SSP. Current energy use (as of 2010) is shown for reference in the far left bar. Data from the SSP database and Riahi et al 2017;
(b) - Global CO2 emissions (GtCO2) for all IAM runs in the SSP database separated out by SSP. Chart via Glen Peters and Robbie Andrews and the Global Carbon Project.
(c) - Global CO2 emissions (gigatonnes, GtCO2) for all IAM runs in the SSP database. SSP no-climate-policy baseline scenarios are shown grey, while various mitigation targets are shown in color. Bold lines indicate the subset of scenarios chosen as a focus for running CMIP6 climate model simulations. Chart produced for Carbon Brief by Glen Peters and Robbie Andrews from the Global Carbon Project.
(d) - Combination of SSP and RCP model runs in the SSP database, with RCPs listed in order of increasing mitigation and SSPs in the (rough) order of increasing mitigation difficulty. Ratios in cells indicate the number of models that succeeded in making the scenario "work" out of the total number of models available for the SSP. Chart by Carbon Brief, adapted from Figure S1 in Rogelj et al (2018).

9.3 Special Report 1.5

In 2018, the IPCC released its "Special Report: Global Warming of 1.5°C"[41] which describes the predicted impacts of global warming of 1.5°C above pre-industrial temperature levels and the related global greenhouse emission pathways to limit warming below 2°C. The report presents its conclusions based on the assessment of the available scientific, technical, and socioeconomic information related to global warming of 1.5°C and 2.0°C. Key findings are excerpted here.

- Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C, and warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, but these emissions alone are unlikely to cause global warming of 1.5°C (medium confidence).
- Climate models project robust differences in regional climate characteristics between the present observed shifts and global warming of 1.5°C, and warming between 1.5° C and 2°C. These differences include increases in: mean temperature in most land and ocean regions (high confidence), hot extremes in most inhabited regions (high confidence), heavy precipitation in several regions (medium confidence), and the probability of drought and precipitation deficits in some regions (medium confidence).
- By 2100, global mean sea level rise is projected to be around 0.1 meters lower with global warming of 1.5°C compared to 2°C (medium confidence). Sea level will continue to rise well beyond 2100 (high confidence), and the magnitude and rate of this rise depend on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas, and deltas (medium confidence).
- Limiting global warming to 1.5°C compared to 2°C is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (high confidence), all of which will reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans.

9.4 State Climate Change Projections

The following climate change discussion summarizes information from NCA4 and NOAA’s state climate summaries (including all data in Figure 9-3).

Alaska

Alaska is on the front lines of climate change and is among the fastest warming regions on Earth. It is warming faster than any other state, and it faces a myriad of issues associated with a changing climate. Global climate models project more warming in the Arctic and interior areas than in the southern areas of Alaska. In the RCP8.5 scenario, interior and northern areas of the state are projected to warm by 10°–16°F, southern portions by 2.5°–8°F. Climate models suggest that Arctic waters will be virtually ice-free by late summer before 2050 and near-surface permafrost will likely disappear on 16% to 24% of the landscape by the end of the 21st century.

Average precipitation is projected to increase in all seasons during the 21st century, with the greatest increases expected in winter and spring. By the middle of the 21st century, annual precipitation increases are projected to exceed 10% over most of the state, with greater increases in the Arctic and interior and the largest increases in the northeastern interior.

Climatic extremes are expected to change with the changing climate. Under a higher scenario (RCP8.5), by mid-century (2046–2065) the highest daily maximum temperature (the hottest temperature one might expect on a given summer day) is projected to increase 4°–8°F compared to the average for 1981–2000. For the same future period (2046–2065), the lowest daily maximum temperature (the highest temperature of the coldest day of the year) throughout most of the state is projected to increase by more than 10°F, with smaller projected changes in the Aleutian Islands and southeastern Alaska. Additionally, the lowest daily minimum temperatures (the coldest nights of the year) are projected to increase by more than 12°F. The number of nights below freezing would likely decrease by at least 20 nights per year statewide, and by greater than 45 nights annually in coastal areas of the North Slope, Seward Peninsula, Yukon–Kuskokwim Delta, Alaska Peninsula, and Southcentral Alaska. Annual maximum one-day precipitation is projected to increase by 5%–10% in southeastern Alaska and by more than 15% in the rest of the state, although the longest dry and wet spells are not expected to change over most of the state. Growing season length (the time between last and first frosts in a given year) is expected to increase by at least 20 days and perhaps more than 40 days compared to the 1982–2010 average. Whether or not this increased growing potential is realized will largely depend on soil conditions and precipitation.

The area burned by wildfires may increase further under a warming climate. Projections of burned area for 2006–2100 are 98 million acres under a lower scenario (RCP4.5) and 120 million acres under a higher scenario (RCP8.5).

California

Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century. Even under a pathway of lower GHG emissions, average annual temperatures are projected to most likely exceed historical record levels by the middle of the 21st century. However, there is a large range of temperature increases under both pathways, and under the lower pathway a few projections are only slightly warmer than historical records. Overall, any warming will lead to increased heat wave intensity but decreased cold wave intensity. Future heat waves could particularly stress coastal communities, such as San Francisco, that are rarely exposed to extreme temperatures and therefore are not well adapted to such events. More intense, longer-lasting heat waves will result in increasing peak demands for electricity for air conditioning, depleting electrical generation and distribution capacities, resulting in increased risks of brownouts and blackouts. The EPA projects that climate change could increase the need for additional electric generating capacity by 10 to 20% by 2050 as a result. Conversely, demand for natural gas, oil, and wood for heating will decrease. Electricity supply also will be affected by changes in the timing of river flows and where hydroelectric systems have limited storage capacity, since increased year-to-year variability of precipitation is expected.

Winter precipitation projections range from slight decreases in southern California to increases in northern California, but these changes are smaller than natural variations. Increasing temperatures are projected to increase the average snowfall elevation, which would reduce water storage in the snowpack, particularly at lower mountain elevations on the margins of snow accumulation. Under the higher scenario (RCP8.5), much of the mountainous area in California with winters currently dominated by snow would begin to receive more precipitation as rain and then only rain by 2050. Higher spring temperatures will also result in earlier melting of the snowpack. The shift in snow melt to earlier in the season is critical for California's water supply because flood control rules require that water be allowed to flow downstream and that water cannot be stored in reservoirs for use in the dry season.

Climate models project an increase in the frequency of heavy downpours, especially through atmospheric rivers, which are narrow bands of highly concentrated storms that move in from the Pacific Ocean. A series of strong atmospheric rivers caused extreme flooding in California in 2016 and 2017. Under the higher scenario (RCP8.5), models project increases in the frequency and intensity of atmospheric rivers.

Droughts are expected to become more intense due to climate change. Even if precipitation increases in the future, temperature rises will increase the rate of soil moisture loss during dry spells, further reducing streamflow, soil moisture, and water supplies. As a result, wildfires are projected to become more frequent and severe.

Increasing temperatures raise concerns for sea level rise in coastal areas. Since 1880, global sea level has risen by about 8 inches. It is projected to rise another 1 to 4 feet by 2100 as a result of both past and future emissions due to human activities. Continued sea level rise will present major challenges to California's water management system. The Sacramento-San Joaquin Delta is the hub of California's water supply system. Water from reservoirs in northern California flows through the Delta where it is then pumped into aqueducts to central and southern California. Sea level rise will cause salty ocean water to intrude into the Delta through San Francisco Bay. This would require increased releases of water from upstream reservoirs to keep the salty water out of the Delta. Water that is used to push salt flows out into the ocean is no longer available for water supply.

Colorado

All climate model projections indicate future warming in Colorado. Statewide average annual temperatures are projected to warm by 2.5°F to 5°F by 2050 relative to a 1971–2000 baseline under RCP4.5. Under the high emissions scenario (RCP8.5), the projected warming is 3.5°F to 6.5°F and would occur later in the century as the two referenced scenarios diverge. Summer temperatures are projected to warm slightly more than winter temperatures, where average temperatures would be similar to the hottest summers that have occurred in the past 100 years. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease continuing recent trends.

Colorado precipitation projections are less clear, with individual models showing a range of changes by 2050 of -5% to +6% for RCP 4.5, and -3% to +8% under RCP8.5. Nearly all models predict an increase in winter precipitation by 2050, although most projections of April 1 snowpack show declines by mid-century due to projected warming. Although heavier winter precipitation could provide important water for the water-scarce Southwest, projected rising temperatures will increase the average lowest elevation at which snow falls (the snow line), with more precipitation falling as rain instead of snow, reducing water storage in the snowpack, particularly at those lower elevations which are now on the margins of reliable snowpack accumulation. Warmer temperatures will also result in earlier melting of the snowpack and increased evaporation of soil moisture, further decreasing water availability during the already dry summer months. Extreme precipitation events are also projected to increase because of increases in the atmospheric water vapor in the oceanic water vapor source regions (due to rising sea surface temperatures) for Colorado's extreme events.

Late-summer river flows are projected to decrease as peak runoff shifts earlier in the season, although the changes in the timing of runoff are more certain than changes in the amount of runoff. In general, most published research indicates a tendency towards future decreases in annual streamflow for all of Colorado's river basins. Projected hotter temperatures increase probabilities of decadal to multidecadal megadroughts, which are persistent droughts lasting longer than a decade, even when precipitation increases. Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, will continue to increase wildfire risks and impacts to people and ecosystems.

Northern Great Plains (Montana, North Dakota, and South Dakota)

The "Fourth National Climate Assessment: Impacts, Risks, and Adaptation in the United States" discusses projected climate change in the Northern Great Plains (consisting of Montana, Wyoming, North Dakota, South Dakota, and Nebraska) in Chapter 22. The impacts of climate change throughout the Northern Great Plains include changes in flooding and drought, rising temperatures, and the spread of invasive species.

Climate projections suggest temperatures will increase throughout the 21st century across the region under all emission scenarios. Temperature increases of 2°–4°F projected by 2050 for the Northern Great Plains under the lower scenario (RCP4.5) are expected to result in an increase in the occurrence of both drought and heat waves. Under a higher emissions pathway (RCP8.5), historically unprecedented warming is projected by the end of the 21st century. The warmest climate model projections indicate average temperatures may increase by over 10°F above the hottest temperatures observed during the 20th century. Temperature increases are projected for all seasons with the most warming indicated during summer. This warming is predicted to occur along with less snowpack and a mix of increases and reductions in average annual water availability.

The "Fourth National Climate Assessment" notes that the amount, distribution, and variability of annual precipitation in the Northern Great Plains are anticipated to change, with increases in winter and spring precipitation of 10%–30% by the end of this century and a decrease in the amount of precipitation falling as snow under a higher scenario (RCP8.5). Summer precipitation is expected to vary across the Northern Great Plains, ranging from no change under a lower scenario (RCP4.5) to 10%–20% reductions under a higher scenario (RCP8.5). The number of heavy precipitation events (events with greater than 1 inch per day) for much of the region is expected to increase. Although fewer hail days are expected, a 40% increase in damage potential from hail due to more frequent occurrence of larger hail is predicted for the spring months by mid-century under a higher scenario (RCP8.5). Even with increases in precipitation, warmer temperatures are expected to increase evaporative demand, leading to more frequent and severe droughts.

New Mexico

Climate models suggest that annual average temperatures in this region may rise by 4°F to as much as 12°F above current levels by the end of the 21st century depending on the emissions scenario. More warming is projected to occur in the northern part of the state. While projections of annual precipitation are uncertain, more precipitation falling as rain is very likely to occur as temperatures increase. Spring precipitation, which is already light in the mountains of New Mexico, is projected to decrease across the state. A decrease in spring precipitation, coupled with higher temperatures, would have negative impacts on mountain snowpack. Even if snowpack accumulation remained similar to current levels, the projected higher temperatures will lead to an earlier start and end to the snowmelt season, potentially necessitating changes in water management.

A recent Bureau of Reclamation report (BOR 2013) made the following projections through the end of the twenty-first century for the Upper Rio Grande Basin (southern Colorado to central-southern New Mexico) based on the current and predicted future warming:

- There would be decreases in overall water availability by one-quarter to one-third.
- The seasonality of stream and river flows would change, with summertime flows decreasing.
- Stream and river flow variability would increase. The frequency, intensity, and duration of both droughts and floods would increase.

The Bureau of Reclamation report also noted that reduction in water is expected to make environmental flows in the Upper Rio Grande system more difficult to maintain and reduce the annual temperatures. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading in Figure 9-3g). Historically unprecedented warming is projected during the 21st century. Less warming is expected under a lower emissions future (the coldest years being about 1°F cooler than the hottest year in the historical record; green shading in Figure 9-3g) and more warming under a higher emissions future (the hottest years being about 10ºF warmer than the hottest year in the historical record; red shading in Figure 9-3g).

Utah

Climate projections under a higher emissions scenario (RCP8.5) indicate that Utah could warm by as much as 15ºF above current levels by the end of the century, though the mean RCP8.5 increase for the state is about 7ºF hotter than recent temperatures. Under a lower emissions scenario, warming is projected to be about 2ºF to 5ºF above the 1991-2020 mean. There is a large range of temperature increases under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in average temperatures will be accompanied by increases in heat wave intensity and decreases in cold wave intensity.

Climate models are not consistent in their projections of precipitation for Utah, including winter precipitation. However, projected rising temperatures will increase the average lowest elevation at which snow falls (the snow line). Continuing recent trends, this will increase the likelihood that precipitation will fall as rain instead of snow, reducing water storage in the snowpack, particularly at lower elevations that are currently on the margins of reliable snowpack accumulation. In addition, extreme precipitation is projected to increase, potentially increasing the frequency and intensity of floods.

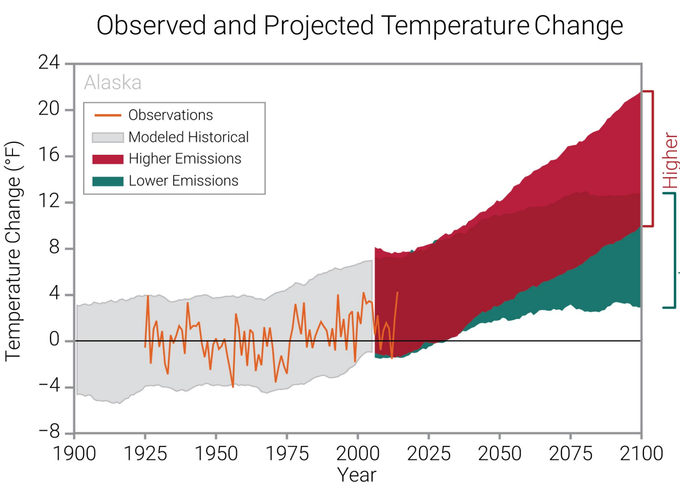
Droughts, a natural part of Utah’s climate, are expected to become more intense. Higher temperatures will amplify the effects of naturally occurring dry spells by increasing the rate of loss of soil moisture. Most of Utah’s water is supplied by the snowpack, and changes to the snow/rain ratio could result in less water storage. Additionally, higher spring temperatures can cause early melting of the snowpack, decreasing water availability during the already dry summer months. The projected increase in the intensity of naturally occurring droughts will increase the occurrence and severity of wildfires.

Wyoming

Under a higher emissions pathway (RCP8.5), historically unprecedented warming is projected by the end of the 21st century. The mean temperature is projected to increase by about 10°F with hottest projections indicating an increase up to 15°F. Even under a pathway of lower greenhouse gas emissions, average annual temperatures are projected to most likely exceed historical record levels by the middle of the 21st century. However, there is a large range of temperature increases under both pathways, and under the lower pathway, a few projections are only slightly warmer than historical records. Increases in heat wave intensity are projected, but the intensity of cold waves is projected to decrease.

Climate models suggest that winter and spring precipitation will increase, which combined with rising temperatures will increase the average lowest elevation at which snow falls. This will increase the likelihood that some of the precipitation events now occurring as snow will fall as rain instead, reducing water storage in the snowpack, particularly at lower elevations. Higher spring temperatures will also result in earlier melting of the snowpack, further decreasing water availability during the drier summer months. Heavier spring precipitation, combined with a shift from snow to rain, could also increase the potential for flooding.

The intensity of future droughts is projected to increase. Even if precipitation amounts increase in the future, temperature increases will intensify evaporation rates, resulting in lower soil moisture during dry spells. Thus, future summer droughts, a natural part of the Wyoming climate, are likely to become more intense. This in turn will increase the risk of wildfires, which are projected to become more frequent and severe. Decreasing snowpack and earlier melt will have regional impacts as the state's abundant snowfall feeds major river systems in the United States.



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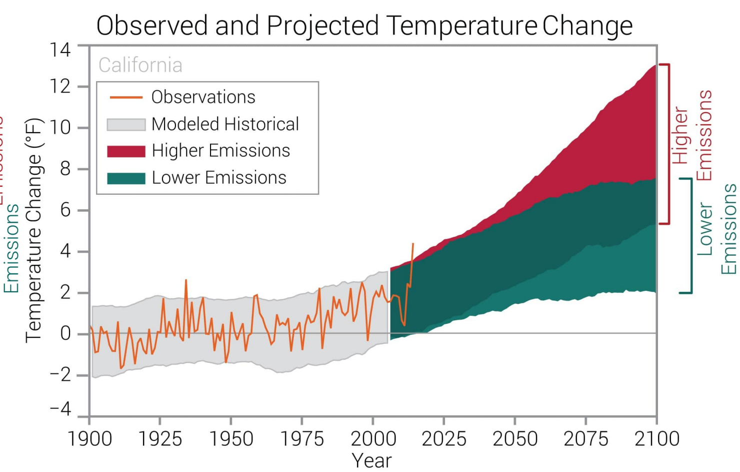

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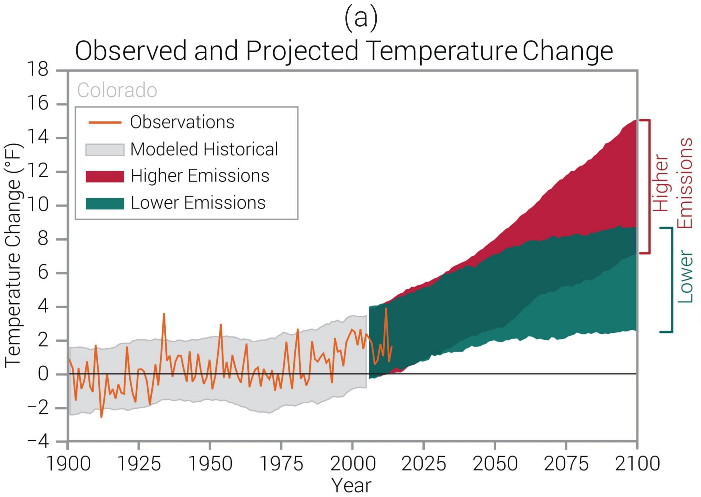

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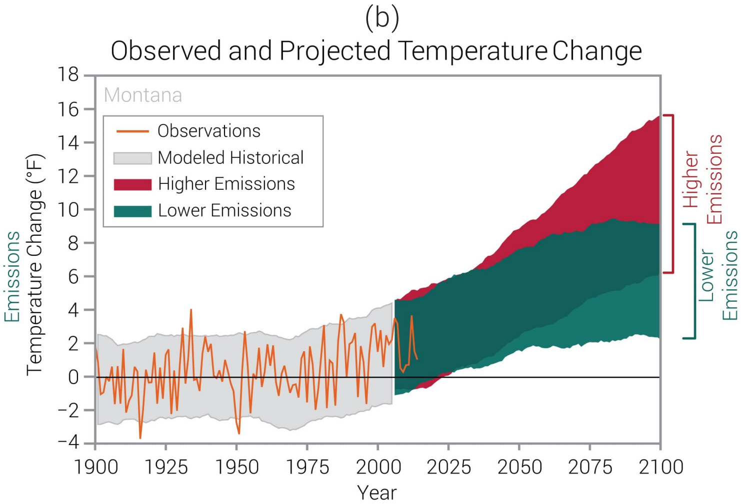

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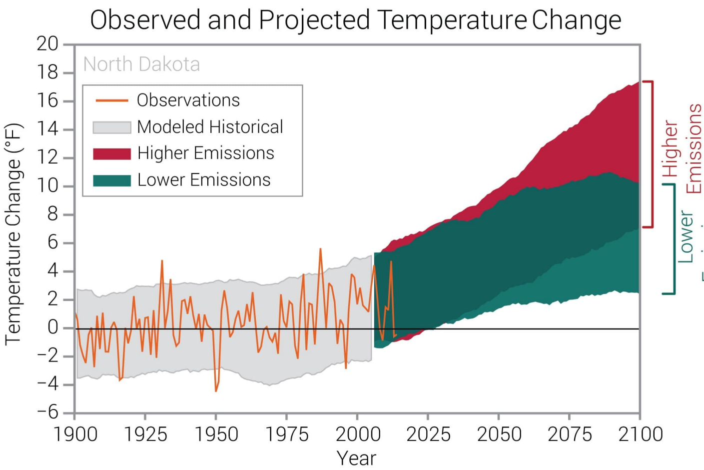

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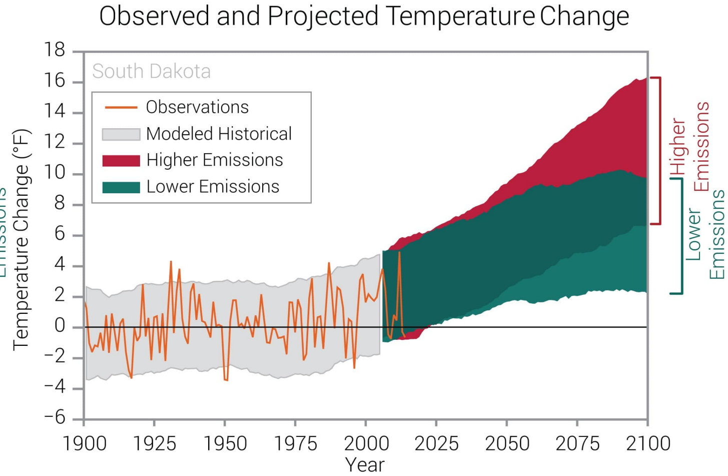

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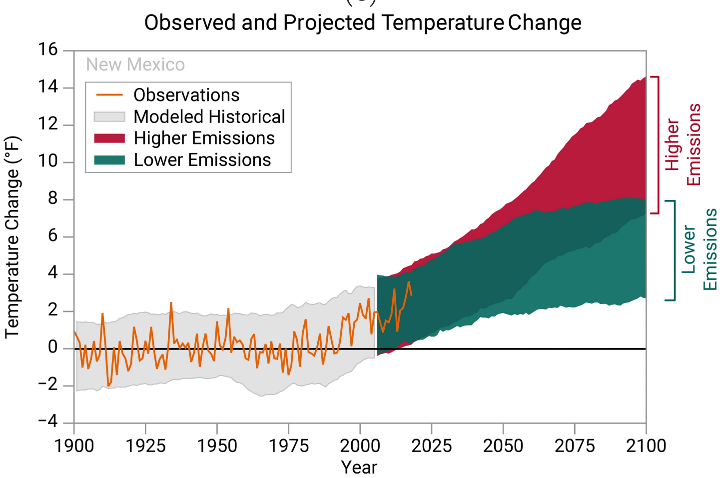

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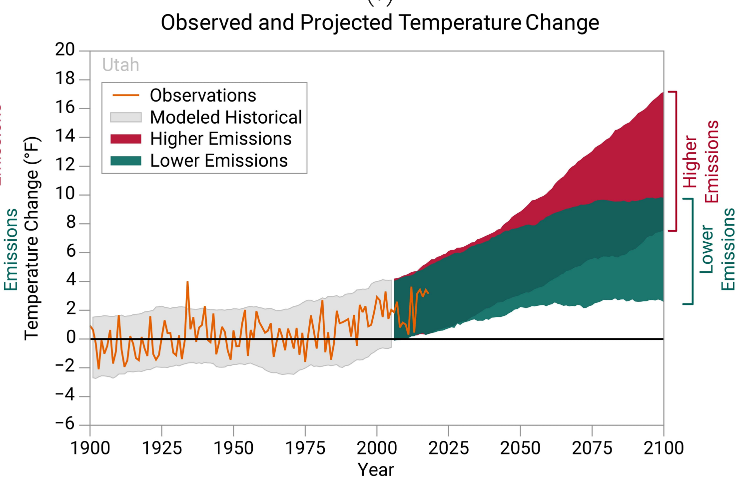

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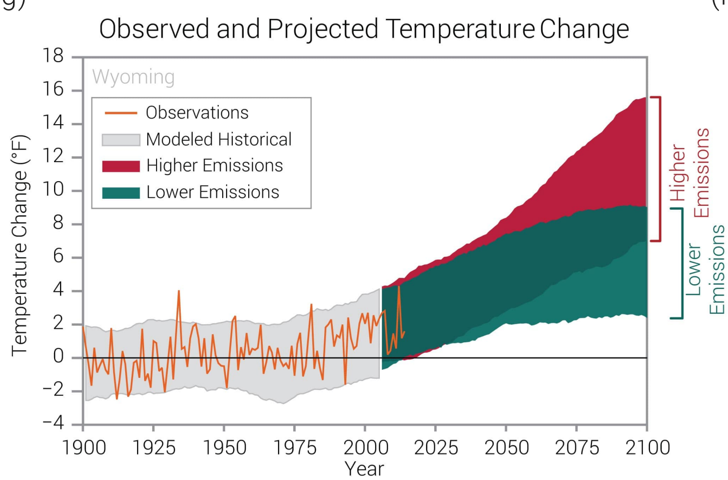

(i)

Figure 9-3. Observed and Projected State Temperatures

9.5 Effects on Public Health and Safety

The following data have been summarized from the Centers for Disease Control and Prevention, Climate and Health website. Climate change and other natural and human-made health stressors influence human health and disease in numerous ways. Some existing health threats will intensify, and new health threats will emerge as a result of climate change. Key weather and climate drivers of health impacts include increasingly frequent, intense, and longer lasting extreme heat, which worsen drought, wildfire, and air pollution risks; increasingly frequent extreme precipitation, intense storms, and changes in precipitation patterns that lead to drought and ecosystem changes; and rising sea levels that intensify coastal flooding and storm surges. Key drivers of vulnerability include the attributes of certain groups (e.g., age, socioeconomic status, race, current level of health) and of place (e.g., floodplains, coastal zones, urban areas), as well as the resilience of critical public health infrastructure. Health effects of these disruptions include increased respiratory and cardiovascular disease, injuries, and premature deaths related to extreme weather events, changes in the prevalence and geographical distribution of foodborne and waterborne illnesses and other infectious diseases, and threats to mental health.

Climate change is projected to affect human health by contributing to degrading air quality in many regions. Increases in dust, pollen and allergens, wildfire smoke, and ground level ozone associated with changes in climate are already being realized in the U.S. Atmospheric warming can increase the formation of ground level ozone which is a GHG and adds to the heat trapping effect. Ground-level ozone (a key component of smog) is associated with many health problems, such as diminished lung function, increases in cardiovascular disease, and increases in premature deaths. Climate change effects including drought, heat waves, and stagnation events can impact air quality causing increased concentrations of particulate matter. Increases in wildfires and associated smoke, drier conditions that create more airborne dust, and changes in vegetation that result in increases in pollen and allergens all contribute to increases in particulate matter in the air. Health effects of particulate matter include asthma, heart disease, lung cancer, and other disease.

Climate change is currently increasing the vulnerability of many forests to wildfire. Climate change is projected to increase the frequency of wildfires in certain regions of the United States. Long periods of record high temperatures are associated with droughts that contribute to dry conditions and drive wildfires in some areas. Wildfire smoke contains particulate matter, carbon monoxide, nitrogen oxides, and various volatile organic compounds (i.e., ozone precursors) and can significantly reduce air quality locally and in areas downwind of fires. Smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits, medical visits for lung illnesses, and medication dispensations for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease (COPD), and respiratory infections.

Drought conditions may increase environmental exposure to dust storms, extreme heat events, flash flooding, degraded water quality, and reduced water quantity. Dust storms associated with drought conditions contribute to degraded air quality. Extreme heat events have long threatened public health in the United States. Heat waves are also associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders. Extreme summer heat is increasing in the United States, and climate projections indicate that extreme heat events will be more frequent and intense in coming decades.

Milder winters resulting from a warming climate can reduce illness, injuries, and deaths associated with cold and snow. Vulnerability to winter weather depends on many nonclimate factors, including housing, age, and baseline health. Although deaths and injuries related to extreme cold events are projected to decline due to climate change, these reductions are not expected to compensate for the increase in heat-related deaths.

The frequency of heavy precipitation events has already increased for the nation as a whole and is projected to increase in all U.S. regions. Increases in both extreme precipitation and total precipitation have contributed to increases in severe flooding events in certain regions. In addition to the immediate health hazards associated with extreme precipitation events when flooding occurs, other hazards can often appear once a storm event has passed. Elevated waterborne disease outbreaks have been reported in the weeks following heavy rainfall, although other variables may also affect these associations. Water intrusion into buildings can result in mold contamination that manifests later, leading to indoor air quality problems. Buildings damaged during hurricanes are especially susceptible to water intrusion. Populations living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms, such as coughing and wheezing, as well as lower respiratory tract infections such as pneumonia, respiratory syncytial virus (RSV), and RSV pneumonia.

Climate is one of the factors that influences the distribution of diseases borne by vectors such as fleas, ticks, and mosquitoes, which spread pathogens that cause illness. The geographic and seasonal distribution of vector populations, and the diseases they can carry, depend not only on climate but also on land use, socioeconomic and cultural factors, pest control, access to health care, and human responses to disease risk, among other factors. Daily, seasonal, or year-to-year climate variability can sometimes result in vector/pathogen adaptation and shifts or expansions in their geographic ranges. North Americans are currently at risk from numerous vector-borne diseases, including Lyme, dengue fever, West Nile virus, Rocky Mountain spotted fever, plague, and tularemia. Vector-borne pathogens not currently found in the United States, such as chikungunya, Chagas disease, and Rift Valley fever viruses, are also potential threats.

Mental illness is a major concern in the United States, and extreme weather events can affect mental health in several ways. For example, research demonstrated high levels of anxiety and post-traumatic stress disorder among people affected by Hurricane Katrina, and similar observations have followed floods and heat waves. Some evidence suggests wildfires have similar effects. All of these events are increasingly fueled by climate change. Additional potential mental health impacts, less well understood, include the possible distress associated with environmental degradation and displacement, and the anxiety and despair that knowledge of climate change might elicit in some people.

* * *

10.0 Mitigation

Much of the current policy on mitigating emissions in the U.S. comes from individual states and municipalities as well as market forcing that results when institutions move assets and future investments away from fossil fuel projects. The BLM's decision space for mitigating climate impacts from fossil fuel development is currently limited by authorization in statutes such as FLPMA and the MLA. The BLM is required to ensure its authorized activities follow the laws and regulations governing GHG emissions, prevent undue waste of federal minerals, and promote efforts to minimize damage to the environment, in general. This chapter discusses the options within BLM's authority for mitigating the impacts of GHG emissions from fossil fuels. Other applicable regulations that limit GHGs under the authority of other federal and state agencies are discussed in Chapter 2.

No single authorized project level action can produce emissions with such significance that the action could be perceived as influencing the climate. However, all GHG emissions (big and small) contribute to changes in atmospheric radiative forcing and ultimately climate change. Even though climate change is a cumulative phenomenon, a project's contribution to climate change can be limited as its net emissions are reduced, with little or no contribution to climate change as net emissions approach zero. Net-zero emissions can be achieved through a combination of controlling and offsetting emissions. Controls limit the amount of GHGs that are emitted to the atmosphere, while offsets either remove GHGs from the atmosphere or reduce emissions in other areas.

GHG emissions from individual BLM-approved actions may be subject to reductions or potential prevention by selecting a reasonable alternative that responds to the action's purpose and need and applying appropriate mitigation. Guidance on how to consider this in NEPA documents was presented in the CEQ's guidance dated August 1, 2016 entitled Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews (currently under review). However, the BLM has limited ability to provide for meaningful or measurable mitigations actions in the context of cumulative climate change resulting from global emissions. Indeed, as shown in Chapters 5 and 6, the production related emissions on the federal mineral estate represent a small percentage of the U.S. and global emissions resulting from fossil fuel energy demand.

10.1 Emissions Reduction Potential

The majority of GHG emissions resulting from federal fossil fuel authorizations occur outside of the BLM's authority and control. These emissions are referred to as indirect emissions and generally occur off-lease during the transport, distribution, refining, and end-use of the produced federal minerals. The BLM's decision space for the downstream emissions is limited to either selecting the no action alternative (i.e., not authorizing lands for fossil fuel development), or choosing alternatives with offsets for portions of the emissions. The various strategies available to the BLM for offsetting emissions are subsequently described.

The BLM's decision authority primarily covers the direct or on-lease portions of natural gas and petroleum systems. The BLM has developed best management practices (BMPs) designed to reduce emissions from field production and operations for on-lease activities. BMPs may include limiting emissions on stationary combustion sources, mobile combustion sources, fugitive sources, and process emissions occurring on a lease parcel. Analysis and approval of future development on the lease parcels may include application of BMPs within the BLM's authority, as conditions of approval, or controls, to reduce or mitigate GHG emissions. Additional measures developed at the project development stage also may be incorporated as applicant-committed measures by the project proponent or added to necessary air quality permits.

Mitigation measures to reduce direct GHG emissions from oil and gas operations may include the following:

- Flare hydrocarbon and gases at high temperatures in order to reduce emissions of incomplete combustion through the use of multichamber combustors.
- Require that vapor recovery systems be maintained and functional in areas where petroleum liquids are stored.
- Install of liquids gathering facilities or central production facilities to reduce the total number of sources and minimize truck traffic.
- Use natural gas fired or electric drill rig engines.
- Use selective catalytic reducers and low-sulfur fuel for diesel-fired drill rig engines.
- Implement directional and horizontal drilling technologies whereby one well provides access to petroleum resources that would normally require drilling several vertical wellbores.

Additionally, the BLM encourages oil and natural gas companies to adopt proven cost-effective technologies and practices that improve operation efficiency and reduce natural gas emissions, to reduce the ultimate impact from the emissions. The EPA reports that 89% of the CH_4 reductions came from the oil and gas production sector. By utilizing a variety of technologies including, reduced blow down frequency, installing vapor recovery units, and converting gas-driven pumps to electric, mechanical, or solar driven pumps operators can develop innovative project design features to self-limit their emissions. The BLM will continue to work with industry to promote the use of the relevant BMPs for operations proposed on federal mineral leases where such mitigation is consistent with agency authorities and policies.

10.2 Offsetting Emissions

In addition to controlling or preventing emissions, strategies to offset emissions could be utilized to align BLM decisionmaking with the goal of achieving net-zero emissions by 2050. The following are various strategies available to the BLM for offsetting emissions. These strategies may or may not be useful for offsetting emissions from individual leases, and other carbon offset strategies may exist beyond those listed here.

Carbon Sequestration

In 2018, the U.S. Geological Survey (USGS) produced a report estimating GHG emissions and sequestration on Federal lands from 2005 to 2014. The report provides net ecosystem productivity (NEP) factors for all federal lands in the United States. Net ecosystem productivity (NEP) is the amount of CO_2 converted to fixed carbon by the terrestrial ecosystem and is the product of CO_2 converted to carbon through photosynthesis minus the release of CO_2 back into the atmosphere from plant respiration and the decomposition of dead organic matter. The report also provided details on land use changes and land cover changes (LULC) which are typically brought on by wildfires, harvest, and general land development. LULC reduces the effective rate of NEP and is reported as net biome productivity (NBP). NBP is the final figure used in the USGS report to calculate the net emissions between federal fossil fuel emissions and the sequestration capacity of the federal lands. Here the BLM is attempting to do the same type of calculation for the report year emissions. Although the NBP data is a few years old and conditions on the ground may have changed in some regions of the U.S., it is the best data available to show region-by-region sequestration and net emissions estimates. As atmospheric concentrations of GHGs increase in the future, terrestrial ecosystems will generally sequester a smaller percentage of emissions. Table 10-1 shows the average annual NEP and NBP from 2005 to 2014 and average NEP and NBP per acre of land in different states and the nation. Averages of the datasets are presented because factors such as wildfires can be highly variable between years. The negative values indicate the sequestration capacity for the areas shown. At the national level, the USGS estimates that terrestrial ecosystems (forests, grasslands, and shrublands) on federal lands sequestered an average of 195 Mt CO_2/yr between 2005 and 2014, offsetting approximately 15% of the CO_2 emissions resulting from the extraction of fossil fuels on federal lands and their end-use combustion. In the absence of site-specific data, the average values per acre could be used to provide an estimate of sequestration for individual lease parcels.

Table 10-1. Carbon Sequestration Capacity of Federal Lands (Mt CO_2e)

State	Federal Owned Acreage	Mean NEP	NEP per acre	Mean NBP	NBP per acre
Alaska	222,666,580	-63.7	-0.28608	-18	-0.08084
California	45,493,133	-30.67	-0.67417	-14.51	-0.31895
Colorado	24,100,247	-16.57	-0.68754	-13.84	-0.57427
Montana	27,082,401	-23.47	-0.86661	-18.85	-0.69602
New Mexico	24,665,774	-3.73	-0.15122	-2.15	-0.08717
North Dakota	1,733,641	-2.85	-1.64394	-1.82	-1.04981
Utah	33,267,621	-10.76	-0.32344	-8.58	-0.25791
Wyoming	29,137,722	-12.11	-0.41561	-10.39	-0.35658
Nationally	615,301,953	-342.93	-0.55734	-194.76	-0.31653

Federal Acres Source: Research Service 2020 report on Federal Land Ownership: Overview and Data[42]

Historically, natural carbon sequestration in plants and soils has been able to lock up about 29% of all anthropogenic emissions on a global scale. Natural sequestration is important because it offers a potential path forward to help mitigate the impact of CO_2 emissions and may play a long-term role in fighting climate change. The Trillion Trees initiative is an example of an enhanced natural sequestration effort. This multinational initiative seeks to reverse deforestation by planting and protecting one trillion trees by 2050. The campaign claims that conserving intact forests, ending deforestation, and restoring trees and natural ecosystems can provide about one-third of the solution to climate change by removing excess CO_2 from the atmosphere. Nationally, restoring forests and ecosystems devastated by wildfires could aid in this effort. What remains unclear is how climate change will impact regional environments and their ability to sustain historical or enhanced sequestration levels going forward.

Plugging Orphaned and Abandoned Wells

The EPA, in its "Inventory of U.S. GHG Emissions and Sinks" annual report, estimates that abandoned oil and gas wells emitted 263,000 tonnes of CH_4 and 7,000 tonnes of CO_2 in 2019. Using AR5 GWPs, abandoned wells emitted 7.4 Mt CO_2e in 2019. However, not all the wells classified as abandoned by the EPA are at the end of their operational life. Some wells may be idled or shut-in and will return to production status, and others may be turned into disposal wells. Plugging abandoned wells that are not expected to be used again could reduce the overall emissions from federal lands.

There is limited emissions data to support emissions factors by oil and gas basin or production type. The EPA uses information from the Townsend-Small et al. 2016[43] study which measured emissions from 138 abandoned wells in the Powder River Basin in Wyoming, Denver-Julesburg Basin in Colorado, Uintah Basin in Utah, and Appalachian Basin in Ohio. The study authors developed emissions factors for well categories observed to exhibit significantly different emissions levels: plugged versus unplugged (including inactive, temporarily abandoned, shut in, dormant, orphaned, and abandoned), in eastern and western U.S. regions. The authors used statistical bootstrapping on the data (sampled emissions rates) to provide factors with a 95% upper confidence limit. Table 10-2 shows the emissions factors from the study. The unplugged wells with the highest GHG emissions are found in the eastern U.S. with a mean emissions rate of 6.87 tonnes (t) CO_2e/yr/well. Wells on federal land which are predominately in the western U.S. have a mean emissions rate of 0.42 tonnes CO_2e/yr/well, which is 6% of the emissions of an unplugged well in the eastern U.S.

Table 10-2. Potential GHG Emissions from Orphaned and Abandoned Wells

Well Category	Mean (g/hr/well)	95% Upper Confidence Limit (g/hr/well)	Mean (t CO_2e/yr/well)	95% Upper Confidence Limit (t CO_2e/yr/well)
All wells (entire U.S.)	1.38	3.17	0.34	0.78
All wells (eastern U.S.)	14	32.87	3.43	8.06
All wells (western U.S.)	0.18	0.41	0.04	0.10
Plugged wells (entire U.S.)	0.00	0.01	0.00	0.00
Unplugged wells (entire U.S.)	10.02	22.47	2.46	5.51
Plugged (eastern U.S.)	0	NA	0	NA
Unplugged (eastern U.S.)	28.01	64	6.87	15.7
Plugged (western U.S.)	0.00	0.01	0.00	0.00
Unplugged (western U.S.)	1.71	3.83	0.42	0.94

Source: Townsend-Small et al. (2016)

Energy Substitution

Overall, GHG emissions could be reduced if fossil fuel energy production is avoided by substituting the use of lower emitting forms of energy. The National Renewable Energy Laboratory (NREL) reviewed and summarized life cycle assessment (LCA) emissions of different electricity generating technologies to reduce uncertainties around estimates of environmental impacts and increase the value of the LCAs in decisionmaking. The LCAs provided in Table 10-3 show the amount of GHG emissions from different types of electrical grid energy sources. Even renewable energy sources, referred to as carbon neutral, emit some GHGs during facility construction, maintenance, decommissioning, and from transportation and distribution of energy. Of these energy sources, the BLM offers leases for coal, oil and gas, geothermal, wind, and solar.

Table 10-3. GHG Emission Factors for Comparison of Electrical System Energy Sources

	Coal	Natural Gas	Biopower	Geothermal	Wind	Solar	Hydro	Nuclear
grams CO2e/kWh	980	465	40	11 - 47	11	27 - 44	7	12

Source: NREL

Over the past decade the energy sector has seen a decrease in annual GHG emissions as energy production from coal has decreased while energy production from natural gas and renewables has increased. Over the short term the trend of an increasing mix of natural gas and renewable energy production is expected to continue, eventually transitioning to mostly renewables in the long term.

The BLM keeps statistics on the designed electric generating capacity of existing and pending wind, solar, and geothermal projects on BLM-managed lands. A summary of the generating capacity for each renewable is provided in Table 10-4. If the renewable projects replace existing fossil fuel energy production and reduce the demand for federal fossil fuels, the potential foreseeable emissions reductions would range from 11.9 Mt CO_2e for replacing Natural Gas energy production to 25.9 Mt CO_2e for replacing coal energy production.

Table 10-4. Electric Generating Capacity of Federal Lands

	Existing Capacity (Mega Watts)	Pending Capacity (Mega Watts)	Potential GHG Reduction Compared to Coal (Mt CO_2e)	Potential GHG Reduction Compared to Natural Gas (Mt CO_2e)
Geothermal	1,235	727	6.07	2.79
Solar	2,656	1,380	11.52	5.29
Wind	1,088	993	8.29	3.81
Total	4,979	3,100	25.88	11.89

Source: https://www.blm.gov/programs/energy-and-minerals/renewable-energy

Carbon Capture

In addition to efforts to better respond and adapt to climate change, other federal initiatives are also being implemented to mitigate climate change. The Carbon Storage Project was implemented to develop carbon sequestration methodologies for geological (i.e., underground) and biological (e.g., forests and rangelands) carbon storage. The project is a collaboration of federal and nonfederal stakeholders to enhance carbon storage in geologic formations and in plants and soils in an environmentally responsible manner. The Carbon Footprint Project is an effort to develop a unified GHG emission reduction program for the DOI, including setting a baseline and reduction goal for the Department’s GHG emissions and energy use. Some research has shown that coal-fired power plants using carbon capture and sequestration (CCS) technology can reduce GHG emissions by approximately 80% compared to coal-fired power plants without CCS technology. While CCS technology is still in the early adoption stage, it does show potential for reducing GHG emissions.

Another form of carbon capture includes recovering and using coal mine methane (CMM). The main idea behind capturing CMM is to recover methane that would otherwise be released from a coal seam and leak into the atmosphere. The recovered methane would then be combusted which converts the methane to carbon dioxide and water, less potent GHGs. Technology is readily available to recover and use CMM. Specific CMM end-uses depend on the gas quality, especially the concentration of methane and the presence of contaminants. Worldwide, CMM is most often used for power generation, district heating, boiler fuel, or town gas, or it is sold to natural gas pipeline systems.

Compensatory Mitigation

Compensatory mitigation is the process of offsetting adverse impacts by replacing or substituting the affected resource or environment through a proponent's offsite actions, monetary payments, or in-kind contributions. Some examples of compensatory mitigation for GHG emissions include plugging orphaned and abandoned wells, purchasing carbon offsets, or supporting land improvement projects that maximize carbon sequestration. Prior BLM policy stated that compensatory mitigation could only be applied at the development stage if the project proponent offered it as a component of a development plan or if it was required by state or federal laws other than FLPMA (BLM Instruction Memorandum (IM) 2019-018, "Compensatory Mitigation"). However, Secretarial Order (SO) 3398, "Revocation of Secretary's Orders Inconsistent with Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis" (April 16, 2021), rescinded SO 3349, "American Energy Independence" (March 29, 2017), and SO 3360, "Rescinding Authorities Inconsistent with Secretary's Order 3349" (December 22, 2017), which IM 2019-018 was based, and the BLM issued IM-2021-038 on July 14, 2021, rescinding the previous IM-2019-018. The BLM expects to establish policies which are aligned with EO 13990, SO 3398, and the priorities of the Department. During this interim period offices should consider and implement compensatory mitigation on a case-by-case basis, in consultation with state office and national office program specialists and the Office of the Solicitor as needed.

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Glossary of Terms

abandoned - An oil or gas well is considered abandoned when it has been permanently taken out of production.

actual fossil fuel production - federal oil and gas lease that is considered to be in an “actual production” status whenever it contains one or more wells drilled on a lease or agreement (communitization or unitization) basis which are producing oil and/or gas in paying quantities. A lease is also considered to be in “actual production” status whenever it contains one or more wells drilled on a lease or agreement basis, which are capable of producing oil and/or gas in paying quantities even though production is not then occurring (BLM Handbook H-3100-1, 'Oil and Gas Leasing').

albedo - The fraction of light that is reflected by a body or surface. It is commonly used in astronomy to describe the reflective properties of planets, satellites, and asteroids. It is also an important consideration in climatology since recent albedo decreases in the Arctic have increased heat absorption at the surface.

anthropogenic - relating to, or resulting from, the influence of human beings on nature.

applications for permit to drill (APDs) - A revocable authorization to use public land for a specified purpose.

carbon dioxide equivalents (CO2e) - A method to express the impact of each different greenhouse gas (methane, nitrous oxide, etc.) in terms of the equivalent amount of CO_2 emissions that would create the same amount of warming of the atmosphere.

climate feedbacks - Feedback in general is the process in which changing one quantity changes a second quantity, and the change in the second quantity in turn changes the first. For example, a positive feedback in global warming is the tendency of warming to increase the amount of water vapor in the atmosphere, which in turn leads to further warming.

completions - Well completion is the process of making a well ready for production (or injection) after drilling operations are completed. This may include hydraulic fracturing.

confidence limit - In statistics, a confidence interval is a type of estimate computed from the observed data. This gives a range of values for an unknown parameter. The interval has an associated confidence level that gives the probability with which an estimated interval will contain the true value of the parameter.

cryosphere - The part of the earth's surface characterized by the presence of frozen water, including mountain glaciers and continental ice sheets, seasonal snow and ice cover on land, and sea ice.

decline - Once an oil and gas well has been completed (the process of making a well ready for production), its maximum production level can be attained within days or weeks. After this level has been reached (transient flow period), there is a decline in production usually caused by loss of reservoir pressure or changing volumes of produced fluid. The rate of production decline is depicted by a decline curve. Decline curves generally show the amount of oil or gas produced per unit of time, for many successive periods.

direct emissions - GHG emissions that are emitted from the development of coal, oil and gas on the federal mineral estate (i.e., onsite mining or upstream operations).

downstream - Includes GHG emissions from refining, distributing, and retail of extracted minerals. This includes oil refineries, gas processing plants, products distributors, and natural gas distribution companies. Downstream emissions also include end uses such combustion of fuels (gasoline, diesel, etc.), plastics, pharmaceuticals, natural gas, and propane.

estimated ultimate recovery (EUR) - The estimated quantity of expected total production from an oil or gas reserve or well. The EUR for a well is calculated as the sum of the observed monthly production values plus the sum of the monthly production values estimated using the decline curve, starting the month after the last observed production month through month 360 (30 years in total).

federal lands - All lands and interests in lands owned by the United States which are subject to the mineral leasing laws, including mineral resources or mineral estates reserved to the United States in the conveyance of a surface or nonmineral estate (43 CFR §3160.0-5).

federal mineral estate - The onshore subsurface mineral estate owned by the Federal government and managed by the BLM, regardless of surface ownership.

fiscal year - A one-year period that companies and governments use for financial reporting and budgeting. The Federal government defines a fiscal year as the period between October 1st to September 30th.

fugitive emissions - Emissions of greenhouse gases that are not produced intentionally by a stack or vent and may include leaks from industrial sources and pipelines (IPCC, 2006).

held-by-production - A provision in an oil or natural gas property lease that allows the lessee, generally an energy company, to continue drilling activities on the property as long as it is economically producing a minimum amount of oil or gas. The held-by-production provision thereby extends the lessee's right to operate the property beyond the initial lease term.

indirect emissions - GHG emissions that are a consequence of the produced fossil fuels but occur downstream from the point of production on federal lands and/or are outside of BLM's approval authority.

leases - An authorization to possess and use public land for a period of time sufficient to amortize capital investments in the land.

life-cycle assessment - A methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service. For instance, in the case of a manufactured product, environmental impacts are assessed from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).

megajoules (MJ) - A megajoule is a derived unit of energy in the International System of Units. One joule is equal to the energy transferred to (or work done on) an object when a force of one newton acts on that object in the direction of the force's motion through a distance of one meter, and thus a megajoule is one million times greater.

megatonnes - A tonne; symbol: (t) is a metric unit of mass equal to 1,000 kilograms. It is also referred to as a metric ton. It is equivalent to approximately 2,204.6 pounds, or 1.102 short tons (US). Mega is multiple of 10^6, and thus a Megatonne; symbol: (Mt), is equal to one million metric tons.

multiple use and sustained yield - A combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources, including recreation, range, timber, minerals, watershed, and wildlife and fish, along with natural scenic, scientific, and historical values.

operators - Any person or entity including but not limited to the lessee or operating rights owner, who has stated in writing to the authorized officer that it is responsible under the terms and conditions of the lease for the operations conducted on the leased lands or a portion thereof (43 CFR §3160.0-5).

parcels - The name given to an area of land made available for competitive or noncompetitive leasing (BLM Handbook H-3100-1, 'Oil and Gas Leasing').

plugged - A well is plugged by setting mechanical or cement plugs in the wellbore at specific intervals to prevent fluid flow.

producible well - A well producing oil or gas, or if not producing oil or gas, a well either declared or capable of being declared producing.

public lands - Any land and interest in land owned by the United States within the several States and administered by the Secretary of the Interior through the Bureau of Land Management, without regard to how the United States acquired ownership, except (1) lands located on the Outer Continental Shelf; and (2) lands held for the benefit of Indians, Aleuts, and Eskimos (43 U.S.C §1702, Federal Land Policy and Management Act of 1976, Sec. 103 (e)).

reasonably foreseeable development scenario - A technical report containing a long-term projection (scenario) of a particular use of the public lands, in this case oil and gas exploration, development, production, and reclamation activity (BLM Handbook H-1624-1, 'Planning for Fluid Mineral Resources').

snow-water equivalents - April 1 snow-water equivalents (SWE) are used as a surrogate for the total seasonal precipitation accumulation and for the maximum seasonal snowpack on the ground.

spud - Spudding is the process of beginning to drill a well in the oil and gas industry.

stoichiometric - Stoichiometry is the study of the quantitative relationships or ratios between two or more substances undergoing a physical change or chemical change (chemical reaction).

teleconnections - A weather pattern that refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. Thus, they are often the culprit responsible for abnormal weather patterns occurring simultaneously over seemingly vast distances.

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Appendix

Link to DB: Spreadsheet

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